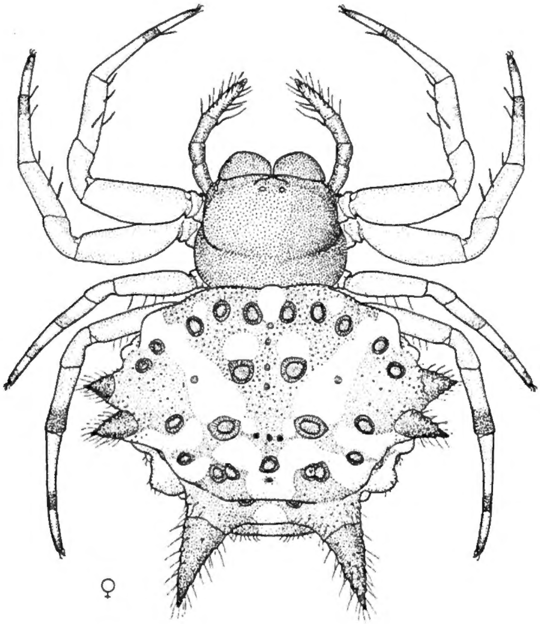
PROCEEDINGS OF THE ROYAL SOCIETY OF QUEENSLAND



2018

VOLUME 123

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PROCEEDINGS OF THE ROYAL SOCIETY OF QUEENSLAND

Editor: Dr. B. Pollock

Special thanks are extended to the anonymous referees who reviewed papers submitted for publication in this volume of the *Proceedings*.

2018

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COVER ILLUSTRATION
Austracantha minax (Australian Christmas Jewel Spider) is a common and much-loved spider throughout Australia, sometimes found in large groups (with overlapping webs) in a range of habitats. Sizes: ♀ 8 mm ♂ 4 mm. Colour photographs of this spider are contained in the book "A Field Guide to Spiders of Australia" by Robert Whyte and Greg Anderson which is reviewed in this volume of the *Proceedings*. The front cover illustration was drawn by Sybil Monteith and is published in Davies, V. Todd. 1988. An illustrated guide to the genera of orb-weaving spiders in Australia. *Mem. Qd Mus.* 25(2): 273-332. Permission of the Queensland Museum to copy this illustration is gratefully acknowledged.

PO Box 6021, St Lucia 4067

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ISSN 0080-469X

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The Royal Society of Queensland has a remarkable history and highly regarded status. It was established in 1883, with royal patronage first granted in 1885, and this has continued unbroken to the present time. The Governor of Queensland His Excellency The Honourable Paul de Jersey AC is the present Patron.

One aim of the Royal Society of Queensland is to progress the natural sciences and scientific knowledge of the natural resources of Queensland. The Society supports scientists and scientific endeavour through advocacy, policy analysis and opinion, scientific seminars and public lectures. The Society is a non-partisan, secular, learned society. The centrepiece of the Society is the production of the scientific journal, *Proceedings of the Royal Society of Queensland*, which is published annually.

Membership is encouraged and open to any person interested in the progress of the natural sciences in Queensland. Members of the Society receive a copy of the Proceedings each year as well as regular newsletters and other information. Membership enquiries should be directed to the Secretary, Royal Society of Queensland, PO Box 6021, St Lucia Q4067. Email rsocqld@gmail.com

Proceedings of the Royal Society of Queensland

The *Proceedings of the Royal Society of Queensland* publishes natural history topics **of relevance to Queensland**, with a very broad range of subjects including biodiversity, conservation, use, management and economic significance of natural resources. All aspects of botany, geology, hydrology and zoology, the biology, impacts and management of introduced species, biomedicine studies and papers on culture and heritage. The journal will also publish papers on general science, including science-related policy, education and philosophy.

All submitted papers are peer reviewed. The following types of manuscripts are considered:
(i) **Scientific Papers** – Full papers containing substantial new data or a substantial review.
(ii) **Short Communications** – Primary research articles reporting discrete items of completed research or topical reports of developments relevant to natural resources in Queensland.
(iii) **Thesis Abstracts** – These short papers aim to disseminate and summarise work performed at the Honours, MSc and PhD level.
(iv) **Opinion Papers and Historical Papers** – Opinion pieces are written as a perspective, not a formal review. These types of papers are of interest to a broad readership, with an emphasis on Queensland relevance.
(v) **Book Reviews** – Authors of books on topics within the scope of PRSQ may contact the Editor to arrange for a book review.

Authors are urged to follow the instructions given in the Guide to Authors which is available on the Society website. Failure to do so may necessitate the return of the manuscript to the author for style revision, and associated delays in publication. The present timelines cover the production of a single volume each year, and require authors to submit their papers to the Editor by 1 July. Following initial appraisal by the Editor, the papers are peer-reviewed by at least two anonymous referees who are experts in the subject. Authors are provided with the reports of referees, and are expected to complete a timely revision where this is necessary. The paper is then typeset and returned to the author for final checking prior to publication. The completed annual volume is published and distributed in December each year. There are no page charges to authors for publication in the *Proceedings of the Royal Society of Queensland*. Authors will be sent a PDF version of the final published paper.

Typeset by Rennie Fletcher
Printed by LitSupport

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PRESIDENTIAL ADDRESS

EDWARDS, G.

INTRODUCTION

There is a common theme running through the subject fields in which the Society has organised deliberative forums during the past year or so – mine rehabilitation, public health, the east coast electricity regime and most recently, management of pastoral lands. In all these prominent fields of public policy, dysfunctional conditions have been festering for years. Governments of both major persuasions have seemed incapable of devising or implementing solutions.

Bernard Keane (2018) in the daily newsletter *Crikey* expressed the current paralysis rather theatrically:

> "Like a form of cosmic background radiation to our public life, there's one issue that is always lurking in contemporary political debates: the seeming inability of governments to get things done. Building a national broadband network. Addressing the disadvantage of Indigenous Australians. Delivering effective climate action. Providing sufficient housing supply. Protecting major river systems. Tasks that have proved beyond governments despite, often, huge amounts of money being thrown at the task."

In this essay I wish to sketch out a model of 'feasible paths', being a set of 'capacities' which must all be available to the responsible operatives if a policy or project is to be successful in its purpose and is to be implemented successfully.

I'm indebted to my former colleague Russell Holland (pers. comm.) for sensitising me to the term 'feasible path' and to the need to identify and satisfy the preconditions if a desired outcome is to be achieved.

CONTEMPORARY EXAMPLE

Governmental incapacity is on plain display in a draft "strategy for nature" published by the Commonwealth's Department of Environment and Energy (BWG 2017), a 17-page piece of fluff proposed to replace Australia's 100-page biodiversity strategy of 2010 (NRMMC 2010). The contemporary version of the strategy commences well enough with a serviceable vision that should appeal as a worthy ideal both to religious conservatives in awe of the Creator's handiwork and secular humanists concerned about the well-being of humans:

> "Australia's nature, now and into the future, is healthy and resilient to threats, and valued both in its own right and for its essential contribution to our health, well-being, prosperity and quality of life."

There follow 12 Objectives which are summarised in "Our approach":

> "Caring for nature is the shared responsibility of all Australians. The aspirations described in this strategy will only be achieved through the joint efforts of governments, communities and individuals."

One would not have guessed! But there is no inventory of the legislative, economic, policy or tools available to "governments, communities and individuals" to progress nature conservation nor an action plan on how to apply them. The nearest the paper approaches to an action plan is to airily opine that "Australia's governments could partner to develop an action inventory to showcase how each government is delivering on ground action against the goals and objectives." In the words of the International Union for Conservation of Nature in a scathing critique (IUCN – Hasham 2018) despite the "fine aspirations", "there is no mention of investments of any kind in the strategy".

The paper also includes no assessment of the dire straits of our natural inheritance to match the eloquence of the "World Scientists' Warning to Humanity: A Second Notice" co-authored by Society member Professor Bill Laurance of James Cook University in 2017 (Ripple et al 2017).

If this is the best response to the past seven years and more of scientific research into biodiversity that the Commonwealth can muster, then our nation's policy capability is in dire straits.

NO FEASIBLE PATH

The core feature that I wish to highlight in this essay is the commonly observed absence of any **feasible path** to connect a high-minded ideal with the instruments available to achieve it. Government reports, federal and state, all too often articulate lofty ideals without assigning personnel or allocating funds to give them effect or to reconcile objectives that are in tension with each other – for example, promises to achieve economic growth while protecting the environment, delivering better services and reducing taxes.

Keane continued:

> "This is the product of decades of neoliberal policy in action, aimed at curbing the role of government. Much of this has been delivered by taking away the tools of governments to accomplish things. We can't build an NBN, for example, because we privatised the government business we traditionally used to roll out telecommunications infrastructure, and, worse, privatised it as a vertically integrated anti-competitive monster. So to build an NBN we had to build a new government business to do it from the ground up. Or we've allowed powerful interests to dictate policy, as in climate policy (well, we don't have a climate policy currently) or the Murray-Darling." (2018).

Neoliberalism – approximating what in Australia is called economic rationalism – is a political philosophy in which an anti-government, pro-business, anti-environmental world view is grafted onto roots in neoclassical economics. It is however a soft target. Yes, neoliberalism's enthusiasm for an idealised model of self-contained individuals managing their well-being through markets, and its antipathy towards solutions mediated by governments, blinds its adherents within the economics profession, business and senior levels of government to the existence of non-market public goods, including many or most elements of the natural environment. Yes, pursuit of its idealised model of competitive markets has led policy woefully astray in fields such as electricity where nationally there is yet no serious economic incentive to reduce carbon emissions or avoid waste. However, there must be some more fundamental reason why neoliberalism's solutions have appealed to our political and policy leaders; and why they keep being attempted, despite repeated evidence of failure. Scapegoating neoliberalism can be self-affirming for non-economists like myself but doesn't carry analysis very far and can blind analysts to the genuine insights that can come from economics, some sub-disciplines more than others.

Did our nation have such difficulty in solving systemic problems in the past? A nostalgic view is that until the neoliberal era of the Hawke government of 1983 onwards, there was a high level of public confidence in Australia as a prosperous, peaceful, knowledge-rich, self-sufficient society, optimistic of human progress and with the ability to adjust policy to continually improve those conditions. It would be possible to advance a counter-argument. Take Medicare, for example. Jamieson (2014) traced "the tortuous introduction of Medibank" in 1975 from earlier initiatives in the 1940s, its abolition by the Coalition, then its replacement by national health insurance in the form of Medicare when the Hawke government came to power. Medicare survives today. One could highlight the previous 35 years of instability in health policy, or the post-1983 period of 35 years of Medicare, creaking but still operating according to its designed structure.

Sidestepping nostalgic assessment of past capacity, in this article I examine what I consider to be a more fundamental weakness in public affairs – fragmentation – than simple pursuit of an inadequate theory of economics. Before articulating this view, I briefly recapitulate a couple of thoughts expressed in previous presidential addresses.

PREVIOUS COMMENTARY

In 2014 (pages 103-106) I referred to the privileged access that representatives of business enjoy to inner policy circles, the undue influence of media proprietors, the ascendancy of the neoliberal prism in national policy and the decline of scientific literacy.

> "The main reason why our leaders in business and government keep making decisions that undermine the life support systems of the planet is that the prevailing world view of the leadership class does not have room for knowledge about those systems – their complexity, their vulnerability to disturbance and their vital importance to the economy. The remedy does not

lie in more scientific research, as facts alone do not change an opinion-leader's world view. Scientific knowledge about the natural environment has already far surpassed the capacity of our political systems to accommodate it."

I concluded by observing that if environmental thinking is to be mainstreamed into the corridors of power, governments must recruit people sensitive to natural sciences in positions of influence; and to build at least a passing knowledge of natural science into the curriculum of those being trained for leadership.

In 2017 (pages 12-14), I referred to the absence of independent forums to bring scientific information to ministers in a form that can be built into policy, and to the "broader, international culture war waged against climate science [that] won't be reconciled by more science". I argued "for establishing (or re-establishing) a capability in Queensland to translate scientific knowledge into policy and decision-making and to build knowledge of scientific method throughout the ranks of parliamentarians and the public service."

In this address I would like to elaborate on the vital role that scientific method should play across all levels of decision-making in our society, across all subject sectors. Scientific method skills its practitioners in tracing cause and consequence, anticipating the effects of acting or not acting in optional directions, evaluating alternatives and mapping the preconditions necessary to achieve desired results.

Scientific method is not the unique preserve of qualified scientists, but education in a scientific discipline helps. Scientific method is more than simply reporting on experiments, although the assemblage of empirical information lies at its heart. Scientific method is more than just reasoning, for reason alone doesn't elevate knowledge above philosophical speculation. Scientific method is more than just avoidance of logical fallacies, although rational analysis is an essential ingredient.

When I was in secondary school, in English classes we studied "Précis writing", a practice that encouraged us to seek to understand a writer's meaning and to identify false logic in written materials. Scientific method is analogous.

Scientific method and an understanding of the preconditions of a successful outcome – an understanding of causation – can be applied to any step in the policy process, from early detection of a problem through to achievement of a preferred solution. When this works effectively, we can say that there is a 'theory of cause and consequence' and a 'feasible path' to apply it.

SOLUTIONS REQUIRE A STRATEGY

To achieve a desired purpose, one can rely on serendipity or strategy. Without denying the power of serendipity or exaggerating the importance of rationalism in public affairs (Saul 1992 reminded us of the vital importance of practical judgement in public affairs), governments need strategies to guide purposeful action, if they are to rise above chaos and the influence of self-interested pressure groups.

An effective strategy will:

1. Set out a realistic vision, an aspiration, a sense of purpose.
2. Be based upon a foundation of coherent theory linking causes and effects and explaining the forces at work, by drawing insights from many disciplines and sources of expertise.
3. Map effective feasible paths for achieving the vision and for overcoming fragmentation of accountability and of knowledge.

Visions are important, for they crystallise the insights of opinion leaders and the strategy's authors. They are rarely the ingredient limiting progress. Time and again visions aren't implemented not because of a deficiency in the vision, but because of the institutional separation of those with the knowledge of the subject field from those with command over the capacities to apply the relevant knowledge. Vision-setting is a decidedly political activity, requiring human judgement and insight beyond scientific knowledge and isn't considered further in this essay.

Formulating the second element of an effective strategy, a coherent theory of cause and effect, requires the application of scientific method, even if the subject lies within the domain of the humanities. Science is the most powerful system yet invented to formulate explanations of causes and effects.

The third element of an effective strategy, the tracing of feasible paths, also benefits from an understanding of cause and effect, even though most scientists would consider it as a decidedly operational function lying outside the domain of scientific investigation. The

reflexive role for scientists is to cast their research into the ether via a refereed publication, and to surrender implementation to others, or to nobody. Implementation is a discipline that rests more comfortably within public administration or organisational management, the seminal text being Pressman & Wildavsky (1973), *Implementation: How Great Expectations in Washington Are Dashed in Oakland; Or, Why It's Amazing that Federal Programs Work at All.*

THE NEED FOR THEORY

Theory is required during policy analysis to sort important from incidental issues and to distinguish fixtures in the institutional arrangements from variables. Some features such as the Australian Constitution are fundamental fixtures: they shape the long-term policy settings and are changed only slowly or with difficulty. Other issues are proximate variables: they are questions of contemporary policy and practice that can be altered by routine process should leaders wish to do so.

Without robust theory to link previous experience, technical information and insights from a range of disciplines, governments can stumble badly, driven by every wind of public opinion or the enthusiasms of lobbyists with a sectoral interest to promote. Large sums of public money can be squandered pursuing inappropriate remedies, such as building prisons to incarcerate young miscreants suffering from medical conditions.

Systemic issues require thoughtful conceptualisation, otherwise solutions become simply patches that may work at a time and place but require continual revision. Without an adequate theory, solutions may or may not work but those involved wouldn't know why, so preconceived ideological positions are conjured up. Put in pithy terms: if the foundational assumptions are invalid, the regime built on them is fragile.

Of all the issues prominent on the Society's agenda in the past year, none illustrates how faulty theory can derail policy more than preventative health. One example can demonstrate the point. For four decades, overweight people have struggled with officially endorsed low-fat, managed-carbohydrate diets that simply don't work. They don't work because they are underpinned by a faulty, overly simplistic theory of carbohydrate metabolism that doesn't adequately account for insulin resistance (Fung 2016).

No social phenomenon is mono-causal. To trace causation through intertwined biophysical and socio-cultural influences, a serviceable theory must draw upon a range of academic disciplines. Reliance upon a single discipline, such as clinical medicine, accountancy or law, to resolve a multifaceted societal problem is a trap for managers in public bureaux with a narrow educational composition.

Theories are derived from observations (evidence), scholarly research and logical analysis. Scanning the contemporary policy landscape, it is possible to identify numerous fields which have been under-theorised, with the result that policy is fractured, unstable, vulnerable to reversal after a change of government and, above all, ineffective. Examples other than preventative health are:

1. Sustainability. This is now just a slogan, with no clear pathway to offset continual conversion of natural capital into manufactured capital; with little official recognition that the very notion of sustainable DEVELOPMENT is an oxymoron; and with little progress in theorising the concept since the *National Strategy for Ecologically Sustainable Development* of 1992.
2. Pastoral land management. Queensland pastoralists manage their properties to produce marketable commodities and are expected to manage the natural capital, including the land, soil, water and atmosphere that form part of the global fabric of life support systems, using the surplus between the prices they receive from markets and their costs. Rising farm debt hints that the 'surplus' is low and decreasing. The markets for commodities follow their own erratic dynamics and are disconnected from the condition of the natural assets upon which production depends. The capacity and willingness of the producer to divert some of the surplus (if any) to regeneration of non-marketable environmental public goods is circumstantial and personal.
3. Centralisation/decentralisation. The distribution of powers between the Commonwealth, the States and local government remains a source of overlap, inefficiency and mismatched funding. When the Commonwealth in 2008 wanted to spend money on insulating houses, it administered the program directly and bypassed the 563 local governments who exercise building control and are staffed with

building inspectors who know the credentials of the contractors in their areas.

A set of theories about how the world functions constitute a person's 'world view'. Leadership factions can share a world view and these tend to frame the set of possible solutions to issues on their agenda. For example, drug addiction can be conceptualised as a personal moral shortcoming (addicts are sinful); or as a sociological shortcoming (addicts' family upbringing was deficient); or as a biomedical shortcoming (addicts' diet or their mothers' diet was deficient). Widely different remedies – incarceration, education, school breakfasts respectively – derive from the different theories of causation.

The neoliberal world view (set of theories) is the prevailing one shared by the governing party in all Australian states and the Commonwealth. I have written of its systemic weaknesses in previous addresses and won't labour that point here.

ELEMENTS OF A FEASIBLE PATH

Governance of Australia's natural resources and environment is un-coordinated. Those who manage the outdoors lack the funds to make sustainability happen. Scientists, design professionals, planners and sociologists who understand how to manage places and communities tend to shy away from involvement in politics. Those who hold the power and the budgetary levers don't understand ecology and in any case are busy promoting economic growth. In looking around, one is impressed by the number and earnestness of capable people labouring to manage our landscapes and environment, but one commonly looks in vain to find any entity which is properly resourced with command over the several required capacities within its area of jurisdiction.

Though committed functionaries will always try to make the best of their circumstances, the absence of any one or more of several essential capacities renders much other capacity impotent. The irreplaceable ingredient is the mandate of a respected coordinator or coordinating body because it can muster the other capacities if any are missing. It can identify the best tools and persuade their administrators to bring them into service of the strategy. It is not essential that it hold all the powers. Yearning for a single benevolent authority is futile as control over the tools will always reside in different bodies; institutional boundaries are required somewhere.

Within the Australian federation, separation of the guardians of the public purse from the operatives who really know and care about the problems requiring remedy and are charged with delivery is endemic. According to the phone book and their website (Treasury 2018), the all-powerful federal Treasury does not even have a public office in Brisbane.

The feasible path model applies to all fields of public policy, but for simplicity the explanation below focuses on natural resources and the environment, the province of natural scientists. For any strategy to be implemented effectively, five capacities are necessary, within the one locus of activity or jurisdiction – say, one study area.

A COORDINATOR

The coordinator motivates the other stakeholders and assembles whatever ingredients are necessary to make progress. The coordinator legitimises the enterprise and accepts responsibility for implementing the strategy.

A crucial task of the coordinator is to scope the exercise or set the geographical and administrative boundaries. A great deal of energy is wasted through mismatch of boundaries. An effective coordinating person or body will encourage existing stakeholders to align their own planning and budget processes to serve the shared task of implementing the vision. For strategic planning exercises, this will often mean aligning spatial boundaries, even if as a subset or superset.

A common reason for the disempowerment of a potential coordinator within a State's administrative apparatus is the involvement of the Commonwealth in implementing strategies that are primarily within the State's operational province. For numerous fields, such as natural resource management, electricity supply and the preventative functions in health, only the State can establish or legitimise a workable regime, but the involvement of the Commonwealth as funder or putative coordinator greatly complicates and potentially weakens the capacity of the State to implement. The prospect of tapping or retaining a pipeline into Commonwealth funding is a powerful disincentive for any State to exercise its responsibilities in those fields where it is sovereign.

Any Commonwealth involvement in a State function reduces the States' accountability, invites cost shifting

and adds exponentially to the transaction costs. State Treasuries can declare that the function is funded by the feds, so they prune the budgets of their local departments further. When the Commonwealth later tightens the fiscal screws or alters the funding criteria, good projects are jettisoned and good people leave, as the States may not make good the shortfall, because their departments would then each have to beg their own Treasuries for brand new initiative funds. The involvement of the Commonwealth in funding natural resource management from about 1997 allowed State Treasuries to progressively reduce their contribution.

The role of coordinator in this typology embraces that of a champion who can command respect from decision-makers and can protect the enterprise from destabilisation by others with different interests to advance. Where the operation has a high public profile, the champion might be separate and remain just a high-profile figurehead without involvement in the practicalities.

The role of coordinator in this typology also embraces that of line command. A person or organisation with acknowledged organisational authority, and, preferably, 'can-do' operational experience, is essential to instruct staff and engage contractors effectively.

The absence of any entity in charge of the east coast electricity regime has afflicted electricity policy ever since the first wave of privatisations. Coordination by a national market regulator with no line command over the generators that are owned or regulated by the states, is hamstrung from the outset.

Where real property or capital assets are to be managed, there is no substitute for ownership, which normally conveys line command. Perhaps the most egregious example of the importance of line command is the saga of fibre-based telecommunications after the privatisation of Telstra dating from 1997. The inability of governments to impose their will on a pugnacious Telstra via third-party regulation induced it to establish its own corporation (NBN) to build a national broadband fibre network, allowing it then to exercise line command. Tens of billions of dollars have arguably been squandered through the disaggregation of Telstra's capacities and erection of various regulatory and advisory bodies endeavouring to exercise some kind of coordination without authority to make things happen.

LEGAL AUTHORITY

In a nation under the rule of law, every operative needs legal authority to conduct works, perform maintenance, tread on land or expend public money. "Legal authority" does not necessarily mean statutory power: most departments operate their administration under royal prerogative without specific statutory origin but administer a range of statutes that both convey and limit their powers to act. Statutory power is however always necessary for coercive actions by the state. To conduct works, the critical legal authority is permission of the landholder. Landholders are sovereign on their properties, enjoying rights to manage and to exclude trespassers that derive from common law (freehold land) or their title (leasehold).

There are some gaps in the suite of statutes available to protect natural resources and environment, but by far the bigger weakness is the unwillingness of governments to adequately fund enforcement of the existing statutes.

CAPABLE PERSONNEL

An instrumental approach to personnel management regards staff as economic units that can be recruited or dismissed according to workflow. By this economistic approach, there is no merit in retaining skilled staff in-house: an authority or firm can always outsource a function to wherever the skills are held, even overseas.

The shortcomings of this clinical, commercial approach to human resource management are well known to any officer who has been a victim of organisational restructure, enforced redundancy, budget cuts or temporary employment, or has participated in a project with stop-start funding. Organisations, public or private are organic systems, not machines. Culture, corporate memory, passion for the work or the work team, dedication to serving the public interest and accumulated years of experience within a field all matter. All this intelligence can be swept aside whenever, say, a government entity applies the 'yellow pages' test: if a private firm can be found to deliver a service, there is no need for the government to retain the capacity.

This is not just a plea from a scientist at the end of his career that agencies should retain mature aged professionals in employment, for any organisation needs a continuous infusion of young talent. It is a plea for stability in staff structures to strengthen

governance, to train a pool of officers ready for the future, to reduce the risk of capture by parochial or sectoral interest groups and to minimise the cruelty that organisational restructures visit upon professional staff who simply want to fulfil their vocation.

Nor is this a plea to build large bureaucracies without recourse to contractors or consultants, as any nimble organisation will be capable of supplementing their own expertise with additional workload capacity or skill sets as required. But there is no substitute for in-house expertise that is on tap without contract overheads, conflict of interest or start-up hiatus. Nor can any contractor match employees on secure tenure for retaining corporate memory or offering disinterested advice.

INFORMATION

Portfolios in government and academe are divided along functional and disciplinary lines. This allows disciplinary technical expertise to flourish and like-skilled people to reinforce each other's skills. Then within organisations, roles are commonly separated along science-policy-operations lines. However, these demarcations – the 'silo effect' – have a significant defect. Natural resources inevitably are managed locally as places, so information from disciplinary specialists must be continually translated into place-based format.

How complicated is this? Fairly complicated, but more to the point, it requires a long-term commitment to embrace that as a mission. This is one activity that is not amenable to delivery through short-term projects. A translator must:

- bridge disciplines and coordinate and meld disparate information from various sources;
- change scale, zooming in from a broader scale to the property scale, or zooming out to feed intelligence back to the centre; and
- interpret information, tracing cause and effect, articulating a theory to explain what is happening, identifying remedies for the problems uncovered and explaining the implications.

FUNDS

While the conventional wisdom that throwing money at a problem doesn't necessarily solve it may well be valid, in a market économy, NOT directing sufficient public money to a problem where collective action is required will nearly always guarantee failure. 'Sufficient money' means budgetary provision or the capacity to secure it easily, for the lifetime of the program.

A budget or revenue-raising capacity is not just one element of a feasible path. It also enables the coordinator or the line commander to procure some of the other necessary elements, notably the skilled personnel (with provisos, see above) and knowledge.

The quantum of money needed to nourish sustainable natural resource management and environmental protection is vanishingly small in comparison with the amount of money that governments spend on the big-ticket construction items such as defence hardware, transport infrastructure and built construction projects. Yet the obstacles that confront a keen scientist in endeavouring to secure funding to implement a new insight arising from their research are immense. Unless the amount required is modest enough to fit into their employer's or sponsor's current budget without supplementation, there may be only one or two opportunities per year to seek funds: the annual budget deliberations and possibly a mid-year review. Within the public service, it is normal practice for Treasury to invite all departments to submit budget proposals twice per year, but with a qualifier to the effect that 'As Treasury will be seeking cuts in your annual appropriation, no new initiatives that have not already been endorsed as a promise of the Government will be entertained'. This exhortation snuffs out the rhetoric of 'innovation', 'smart state' and many of the other high-minded ideals that governments proclaim but without a feasible path to make them happen.

Another obstacle, faced by public servants and non-government entities alike, is the pernicious practice of requiring co-funding from other participating organisations. The time and energies of scientists and others who want to get on with their work are spent in coaxing others to contribute. But other stakeholders have other priorities and their budgetary timelines may be quite mismatched. The case of fire ants exemplifies this corrosive practice.

FIRE ANT CASE STUDY

It is difficult to fathom why governments, having sound scientific advice of the havoc that exotic fire ants are likely to wreak upon economic production and lifestyle in Queensland, would dither over cost-sharing with the other states and the Commonwealth who were not immediately

threatened. Yes, fire ants could colonise virtually all of mainland Australia, rendering it a national threat, but control of pest plants and animals is clearly a state responsibility and fire ants made their landfall in Queensland, several times from 2001. The Queensland Government stepped in quickly in 2001 to commence an eradication program, but once a national program was conceived, urgency faded.

In November 2014, the Commonwealth, apparently not trusting the evidence of Queensland's scientists, commissioned an 'independent' review of the eradication program (IRP 2016). This was on top of 13, repeat 13, previous external reviews of the Queensland program. The report was furnished to ministers in May 2016 but not released until November 2016, and then only after the Senate passed a motion to force the executive to do so. The report found that there was only a small window of opportunity left to eradicate the pest, that a benefit cost ratio of 25 to 1 could be demonstrated and that the failure to achieve eradication to date was "not due to the science, but rather to missed opportunities: the limitations of short-term funding, and a reallocation of funding from eradication to delimitation...". The lack of funds for eradication allowed the ant to re-infest localities from which they had been destroyed.

All nine governments were required to come to a unanimous decision to boost funding by the requested amount deemed adequate to achieve eradication within 10 years, a derisory $20 million per year (Invasive Species Council 2017). The funding plan was finally signed in 2017. Canegrowers (2017) reported that prior to that budget injection, cane farmers in the Rocky Point District south of Brisbane were waiting up to 60 days for an inspector to visit reported nests. Western Australia ceased their contribution for three years prior to 2017 because they thought they could keep the ants from reaching their state. A refreshed commitment from Western Australia was delayed by their March 2017 election.

It is incomprehensible that our society allows its natural resource management to be subjected to such inefficient and ineffective budgetary procedures, in this case especially given that Queensland scientists recognised the economic and environmental threat immediately upon discovery of the first incursion in 2001. It is incomprehensible that the conclusions of an authoritative report dated May 2016 advocating that there was only a narrow window of opportunity to prevail over this pest were not implemented as a matter of national emergency.

The 'national coordination' in this case study seemed to have been an obstacle to speedy and effective action. In biosecurity, this weakness may be systemic. In a news report on the interception of Varroa Mite in the Victorian docks (Rooth 2018), there is an implication that the Commonwealth coordinating entity could not coordinate any sense of urgency between the States on a matter of paramount importance to the apiary and horticulture industries.

Testing our model of feasible paths through the fire ant case study, it can be seen that a number of elements were missing. Vision? A vision of eradication was easy to develop. Theory? Science was equal to the task: there was a scientific theory to underpin eradication efforts, strengthened through research into treatment methods as the program unfolded. Arguably, however, the economic theory underpinning national biosecurity programs has been deficient, firstly based as it seems on risk management (IRP 2016) and not ecology; and secondly based as it seems on minimising the cost to the Queensland budget by prevailing upon the other states. Champion? There was no obvious champion willing to prosecute the case for adequate funding according to the national model. The national model fragments accountability and is only as strong as its most recalcitrant link. The Commonwealth agency could have been a champion but lacked either legal authority or knowledge or both. Line command? No operator with line command over personnel and resources is visible. Legislation, skilled personnel and knowledge? These have not been limiting factors amongst scientists, but knowledge at the level of decision-makers seem to be lacking. Funds? Funding was the critical shortfall but need not have been if there had been a vigorous state-based champion. The case study demonstrates that it is insufficient to have in-depth scientific knowledge at the periphery if there is no champion at the centre with passion for the task at hand and with the authority to secure the necessary resources for the actions known by experts to be necessary.

The interpretation that most fits these circumstances is not the economic cost of environmental protection measures, as a 25:1 ratio of economic benefits puts most construction projects in the shade. The lack of an empowered, ecologically literate coordinator is the

most plausible explanation. This can be remedied and must be, if our society is to protect the life-support systems of the planet from collapse.

CONCLUSIONS

This essay presents a diagnosis of the reasons why scientists' knowledge of natural resources and the environment is so often not applied or ineffectively applied to protective action. There is a strategic reason: absence of robust theory; and there is an eminently operational reason: absence of one of five critical elements of a feasible path. The lack of an empowered champion or can-do commander or dispersed legal powers can be summarised as fragmented accountability. The lack of skilled personnel or information can be summarised as fragmented knowledge. The lack of funding can be summarised as starvation of public goods.

It is not sufficient to have two or three of these elements in abundance if at a specific locus of activity one of them is lacking. The absence of one or more of these capacities renders so much other capacity impotent. Within the public service, the central agencies of government are best placed to assemble the necessary ingredients and empower champions. Within business, directors exercise this function. It is a matter of vital importance that our society improve the scientific and environmental literacy of those occupying these roles and make them aware of feasible path analysis, so that those with knowledge of the distress that our planet's life-support systems are suffering are empowered to apply remedies.

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"The only thing on our advantage is that it arrived in Victoria, because Victorians are the most

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FACTORS INFLUENCING THE COLONISATION BY SPRINGTAILS OF GREAT BARRIER REEF ISLANDS

KING, K. L.[1] & GREENSLADE, P.[2,3]

The Collembola fauna of ten cays of the Swain Reefs (Great Barrier Reef) were sampled in July 1982 and 1983. Marine littoral Collembola were found on all but two cays. Terrestrial Collembola were sampled quantitatively in 1983 on three cays of increasing degrees of vegetation cover. On the largest well-vegetated cay, collembolan numbers were at least twenty-five times higher than on the less well-vegetated cays. *Xenylla manusiensis,* the overwhelmingly dominant Collembolon among the cays, showed a positive association with organic matter in the sample.

A species list for all coral and volcanic islands from which Collembola have been collected in the Great Barrier Reef is supplied with notes on ecology and distribution. Some marine littoral species are recorded here for the first time. A family signature shows that Isotomidae are the relatively most species rich group collected and Symphypleonan families and Entomobryidae the least. Adaptations to a marine littoral life of some species are described. Management options to protect the fauna, especially short-range endemics, are suggested.

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INTRODUCTION

The Great Barrier Reef, Queensland, Australia, is valued not only for its large size but also for its biodiversity and high degree of endemism and its importance is indicated by its listing as a World Heritage site. The most valued aspect of the biodiversity of the area are the marine fauna especially corals, fish and marine invertebrates. The terrestrial fauna, being largely transient on coral cays, has a low level of endemism but nevertheless there are bird and reptile species of conservation significance (DNPRSR 2013); for example, the Capricorn White-eye and Sadliers Dwarf Skink are endemic to the Capricorn Bunker Group and Magnetic Island respectively (Turner & Batianoff 2007). Threats to the reef and its associated islands that might affect their conservation value include: rising sea temperatures due to global warming (Turner & Batianoff 2007), the discarding of solid wastes from ships and fishing vessels, increasing tourist activity (Environment Australia 2001) and the introduction of invasive species (Greenslade 2010). Although of low frequency, pollutants from oil spills would also have a deleterious effect on the fauna as well as compaction from vehicles and other traffic on beaches (Schlacher & Thompson 2013, Schlacher at al. 2007).

There are two main types of islands comprising the Great Barrier Reef, continental volcanic islands and coral cays. The former were originally part of the mainland and can provide habitat for remnant fauna and flora especially as they have a more complex topography and vegetation while the latter tend to harbour widespread, largely marine littoral species (Thibaud 2007). The origins of the fauna of these two types of island are different as are the types of colonisation events. We investigate here colonisation events of coral cays.

The invertebrate fauna of the islands of the Great Barrier Reef has not been extensively surveyed (Environment Australia 2001) even though most islands and cays are protected and include some rare habitats for some endangered and vulnerable birds and reptiles (Turner & Batianoff 2007). These preliminary surveys suggest that the invertebrate fauna may not be species rich (Environment Australia 2001) but it can be abundant and some species have limited distributions. Only a few islands have been surveyed and we here summarise records of all Collembola species found during these surveys.

The earliest published records for Collembola of the Great Barrier Reef were by Womersley (1939)

TABLE 1. Records of Collembola species from Great Barrier Reff islands

sp. = species distinct but not identified, imm. indet. = species not able to be identified, ? = record uncertain. References below.

Island		**Swain Reefs**	**One Tree Is**	**Herald Group**	**Herald Group**	**Herald Group**	**Herald Group**	**N.E. Herald**	**Herald Group**	**Herald group**	
Family	**Species and authorities**	**King 1982/3**	**Done 1976**	**Heatwole, 1967, 1979, 1981**	**Donaldson 1994**	**Hill 1982**	**Hill 1984**	**Anderson 1997**	**Donaldson, 1995**	**Greenslade & Farrow 2007**	**Total records**
Hypogastruridae	*Acherontiella* sp. cf *prominentia* Thibaud & Weiner					X			X	X	**3**
	Ceratophysella sp.	X									**1**
	Paraxenylla piloua Thibaud & Weiner									X	**1**
	Paraxyenylla sp. cf *affiniformis* Murphy			X	X	X			X		**4**
	Xenylla manusiensis da Gama	X	X	X	X	X		?X	X	X	**8**
Tullbergiidae	*Mesaphorura yosii* Rusek	X	X								**2**
	Tullbergia sp.	X									**1**
Neanuridae	*Oudemansia coerulea* Schött	X	X			X	?X			X	**5**
	Yuukianura halophila Yosii					X	X			X	**3**
	Pseudanurida billitonensis Schött		X			X					**2**
	Anuritelsa maritima Womersley									?X	**1**
	Friesea sp.									X	**1**
	Friesea sp. cf *pins* Thibaud & Weiner									X	**1**
Brachystomellidae	*Brachystomella* sp.1*	X						X	X		**3**
	Brachystomella sp. 2		X								**1**

Island		Swain Reefs	One Tree Is	Herald Group	Herald Group	Herald Group	Herald Group	N.E. Herald	Herald Group	Herald group	
Family	**Species add authorities**	**King 1982/3**	**Done 1976**	**Heatwole, 1967, 1979, 1981**	**Donaldson 1994**	**Hill 1982**	**Hill 1984**	**Anderson 1997**	**Donaldson, 1995**	**Greenslade & Farrow 2007**	**Total records**
Isotomidae	*Folsomina onychiurina* Denis		X							X	**2**
	Archisotoma sp. nr *theae* Fjellberg	X									**1**
	Mucrosomia caeca (Wahlgren)	X									**1**
	Archisotoma sp. cf. *interstitialis* Delamare Deboutteville	X				X				X	**3**
	Axelsonia sp. cf. *australis* Bagnall					X					**1**
	Folsomides exiguus Folsom		X					X	X		**3**
	Isotoma sp. or *Desoria* sp.									X	**1**
	Isotomodes sp.	X									**1**
	Parisotoma sp.									X	**1**
	Folsomides centralis (Denis)		X					?X			**2**
	Psammisotoma kingae Greenslade & Deharveng	X					X				**2**
	Isotopenola sp.	X									**1**
Cyphoderidae	*Cyphoderus* sp.	X									**1**
Entomobryidae	*Entomobrya* sp. imm. indet	X	X								**2**
	Entomobrya atrocincta Schött					X					**1**
	Entomobrya multifasciata (Tullberg)					X					**1**
	Lepidocyrtus (Lanocyrtus) fimetarius Gisin				X	X			X	X	**4**
	Lepidocyrtus sp. 2									X	**1**
	cf. Dicranocentrus n. sp.						X			X	**2**
	Pseudosinella sp.					X		X	X	X	**4**
	Seira sp.									X	**1**

Island		Swain Reefs	One Tree Is	Herald Group	Herald Group	Herald Group	Herald Group	N.E. Herald	Herald Group	Herald group	
Family	**Species add authorities**	**King 1982/3**	**Done 1976**	**Heatwole, 1967, 1979, 1981**	**Donaldson 1994**	**Hill 1982**	**Hill 1984**	**Anderson 1997**	**Donaldson, 1995**	**Greenslade & Farrow 2007**	**Total records**
Katiannidae	*Sminthurinus* sp. cf. *muscoli* Salmon	X	X								2
Dicyrtomidae	*Dicyrtomina* sp.					X					1
Sminthurididae	*Sphaeridia* sp.							X	X	X	3
Bourletiellidae	*Bourletiella viridescens* (Stach)									X	1
Neelidae	*Megalothorax* sp.		X							X	2
Total records	**41**	**15**	**11**	**2**	**3**	**13**	**4**	**6**	**8**	**20**	**82**
	*Possibly *Brachystomella* sp. cf. *unguilongua* Thibaud & Najt										

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of *Oudemansia barnardi* Womersley from coral rocks on West Molle Island (Whitsunday group), *Anuritelsa maritima* Womersley, 1939 from under stones on Rat Island, Port Curtis and *Axelsonia littoralis* (Moniez) from the saline reaches of Auckland Creek on the adjacent mainland; the latter two localities being in the vicinity of Curtis Island and Gladstone, Queensland respectively. Other early collectors were MacKerras (1950) who found two marine littoral species on the reef crest at low tide at Heron Island, Heatwole (1971) who found several species on unvegetated cays of the southwest Coral Sea and Done (1976) who made an ecological study of population changes and species associations of soil arthropods, including Collembola, on One Tree Island. Later, Hill (1981–1984) made fairly intensive collections in the Herald Group (Coral Sea) while a few collections were made on the volcanic Long Island (Whitsundays) (P. Greenslade, unpublished). More recently, Greenslade and Farrow (2007) fully documented the invertebrate fauna of four islands in the Herald group. Other non-coral tropical islands, not in the Great Barrier Reef, that have been surveyed for Collembola were the sandy Sweers Island in the Gulf of Carpentaria (Greenslade, 2005), the tropical, part-coral Barrow Island (Greenslade, 2013) and the sandy Fraser Island (Greenslade, 2017). Collembola species records from the Great Barrier Reef are listed in Table 1.

We report here in detail on several surveys of the Collembola communities found on cays in the Swain Reefs in 1982 and 1983 by the senior author. The ecology, distribution and abundance of the species found are noted. Comments are made on the conservation value of the fauna and factors that determine the colonisation of islands are discussed.

MATERIALS AND METHODS

The Swain Reefs lie between 20°53'S and 22°24'S and 151°15' E and 152°48'E (Flood & Heatwole 1986), approximately 350 km southeast of Mackay, Queensland (Figure 1). It is a complex area of nearly 400 patches of reefs covering over 200 km in length (Figure 1). A few of the reefs are normally above high tide long enough to develop soils with sparse vegetation. These plant communities are comprised of grasses and herbs but may be only transient. Swain Reefs is the only example of this type of vegetation in the southern Great Barrier Reef. A fuller description of the complex is given in Kenchington (1982) and DNPRSR (2013).

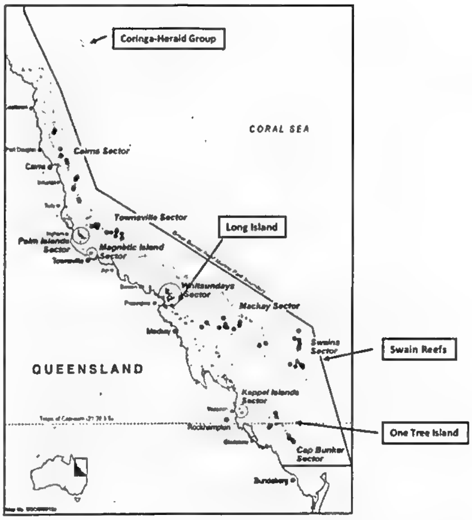

FIG. 1. Map showing location of Great Barrier Reef and island groups in relation to Australia and Queensland (Map No. SCD060813a).

In July 1982 and 1983, Collembola were sampled on cays of the Swain Reefs. Another cay, Bell, was also sampled. It is located outside the Swain Reefs complex, 30 km to the west of these reefs. Rainfall is relatively aseasonal i.e. uniformly distributed throughout the year, with a tendency for winters to be drier than other seasons, and the climate is mild and equable (Done, 1976) with an annual average temperature of 24.6°C ranging between 23.6°C and 25.5°C (https://en.tutiempo.net/climate/2016/ws-943790.html).

The inter-tidal zone of all cays visited (seven sand and three coral rubble) was sampled non-quantitatively for littoral Collembola in July 1982 and July 1983. A pit was dug approximately 30 cm from the water's edge and allowed to fill with seawater. Collembola, which have a hydrophobic cuticle, floated from between the interstices of the sand grains up to the water surface, where they were scooped off with a shallow net (mesh 0.15 mm) and transferred to alcohol.

Three closely situated sand cays were also sampled quantitatively for terrestrial Collembola i.e. those living above the high water mark, in July 1983; a small unvegetated cay (Thomas), a small, vegetated cay (Bacchi) and a large vegetated cay, Gillett (also called Frigate). Thomas and Bacchi were situated 2 km from each other and 14 km north of Gillett.

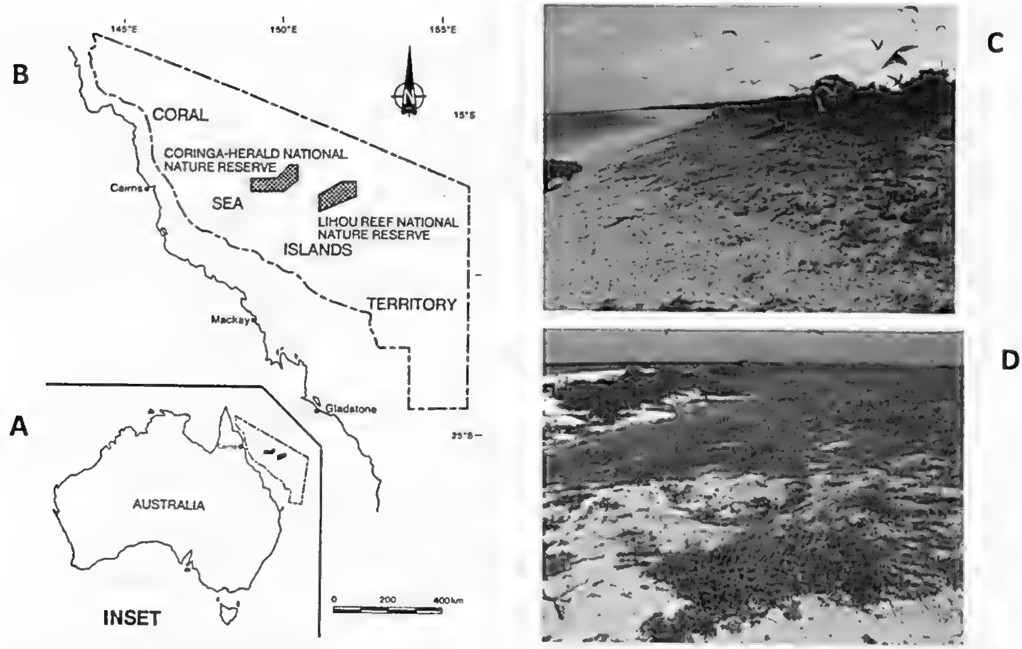

FIG. 2. A. Map of Australia showing location of Coringa Herald and Lihou Reef Reserves in relation to Australia. B. Map showing location of Coringa Herald and Lihou Reef Reserves in relation to Queensland Coast (Batianoff et al. 2010), C and D. view of supralittoral grassland shore on North East Herald Cay, similar habitat to vegetated Cays in Swain Reefs (Photograph P. Greenslade and R. Farrow 2007).

The three cays were located between 21°45' S and 21°35' S and 152°22'E and 152°28'E.

The area of vegetation cover and total cay dimensions are given in Table 2 (Flood & Heatwole, 1986). In July 1984, these authors noted that although the vegetation on Thomas covered 4000 m², this was sparse and composed mostly of dead vegetation. The total vegetated area of Gillett was around six times that of Bacchi (Flood & Heatwole, 1986). The plant species present in the five years prior to 1982 on Gillet and Bacchi were *Boerhavia diffusa* L., *Coronopus integrifolius* (DC.) Spreng. and two grasses *Lepturus repens* (Forst.) R. Br. Prodr. and *Thuarea involuta* (G. Forst.) R. Br. ex Smith. (Figures 2 C,D).

On each of the three cays, ten paired cores (using corers 10 cm diam.) were taken of sand (to 7 cm depth) and any litter and living vegetation that occurred on the surface of the sand core to a plant height of 5 cm. The fauna was extracted using Tullgren funnels (King & Hutchinson, 1976). To measure the quantity of organic matter from each core, they were immersed, after Tullgren extraction, in $MgSO_4$ solution (SG 1.3) whereby organic debris floated to the surface. For determination of dry matter, the floating material was washed with demineralised water, dried at 100°C for 48 hours and weighed. Ash determinations were obtained by combustion in a furnace at 600°C for 16 hours. Organic matter determination was obtained by the difference in weight between dry matter and ash.

Linear Regression analysis was used by hand to examine the relationship between the numbers of the dominant Collembolon (*Xenylla manusiensis*) and the weight of organic matter in the samples. Numbers of Collembola were log transformed to reduce the dependence of the variance on the mean.

RESULTS

Twelve species of terrestrial and four species of marine littoral Collembola (Tables 1, 3 and 4) were collected on the two visits to the Swain Reefs in 1982 and 1983. Species not listed for littoral Collembola in Table 3

TABLE 2. Dimensions of the three Swain Reefs sand cays sampled quantitatively in 1983 (total area, perimeter at junction line of the beach and the reef flat, and the area of the cay which was vegetated) are taken from Flood and Heatwole (1986).

Coral Cay	Thomas	Bacchi	Gillett
Cay area (m^2) 1984	16 800	17 200	42 000
Perimeter (m) 1983	493	811	1009
Live vegetation 1984 (m^2)	0	2 600	14 400

TABLE 3. Occurrence (indicated by +, absence indicated by -) of littoral species of Collembola on ten cays of the Swain Reefs.

Species	*Oudemansia coerulea* Schött	*Archisotoma sp.cf interstitialis*
Sand Cays	+	+
Gannet	+	+
Gillett	+	+
Bell	+	+
Thomas	+	+
Bacchi	+	+
Bylund	+	+
Price	+	+
Coral Rubble Cays		
Herald Prong 2	-	+?
Sunray	-	-
Hixson	-	-

are two unidentified specimens of Entomobryidae and one unidentified Symphypleona. All major families of Collembola were represented with Isotomidae and Hypogastruridae being numerically dominant and with few Symphypleona compared to mainland sites.

On both sampling occasions, intertidal Collembola were found on all seven sand cays but only on a sandy patch of one of the rubble cays (Herald's Prong 2). Table 3 shows the occurrence of the two species of Collembola which were found in the inter-tidal zone.

Table 4 gives the mean abundance for four families of terrestrial Collembola for each cay. Gillett had between 25 to 50 times the total numbers of the other two cays. The bare cay had somewhat higher numbers than Bacchi but the difference was small when compared to the numbers found on Gillett. Isotomid Collembola were dominant on the bare cay and their numbers decreased on the other cays relative to numbers in other families. Identified species on Gillett were *Xenylla manusiensis* da Gama, *Mucrosomia* sp. cf. *caeca* (Wahlgren), *Folsomides exiguus* Folsom, *Isotomodes* sp., *Mesaphorura* sp. and *Cyphoderus* sp. while only *M. caeca* and *Isotomodes* sp. and *Mesaphorura* sp. were found on Bacchi and Thomas respectively. Photographs of some genera of Collembola found are given in Figure 3.

Over 90% of the hypogastrurid Collembola found on Gillett were one species, *X. manusiensis* (Tables 4 and 5). This species showed a positive correlation with amount of organic matter (OM) present in the cores. The regression relationship is as follows:
$\text{Log}(\text{No./m}^2) = 0.968 + 0.00209\,(\text{OM g/m}^2)$. $R=0.745$. The correlation coefficient R was highly significant ($P<0.001$) and organic matter accounted for 50% of the variation in log numbers for the 30 observations.

DISCUSSION

COLLEMBOLAN FAUNAS OF GREAT BARRIER REEF ISLANDS

Table 1 lists all the collembolan species collected and identified from coral and some volcanic islands

in the Great Barrier Reef. Few of these records have been formally published before. In all, 40 species are listed but not all species names have been confirmed. Considering the ephemeral nature and instability of these islands (Flood & Heatwole 1986) and the fact they are subject to considerable impact from cyclones, this number is high, as all species must have arrived by long distance dispersal. Marine littoral species comprise nearly 40% of the total. It is likely that propagules of these species are dispersed on floating marine debris or are wind-blown or even carried by birds (Gillespie et al. 2011). Consequently, many species collected are widespread in the southwest Pacific and so of limited conservation significance for rarity. The most common and abundant species appears to be *Xenylla manusiensis* da Gama, 1967, with eight records. It was described from Manus Island, Papua New Guinea and otherwise is only known from Great Barrier Reef Islands.

Within Australia, there is a boundary between genera typical of tropical regions, (*Oudemansia*, *Anuritelsa*, n. gen. nr *Dicranocentrus*, *Yuukianura*, *Acherontiella*, *Psammisotoma*) and those southern temperate, cool regions (*Hypogastura, Halisotoma, Pseudoparonella).* The genus *Archisotoma* is the most abundant genus on sandy or mud flat beaches in all climatic zones (P. Greenslade, Barrow Island and unpublished data).

Of other marine littoral species *Oudemansia barnardi* Womersley, also occurs in New Caledonia and Vietnam while *Archisotoma* sp. near *interstitialis* Delamare Deboutteville is a cosmopolitan species. A further two Collembola species, which are generally considered to be marine littoral in other parts of the world, were found above high water mark. These are *Archisotoma* sp. near *theae*, whose only other record is from Norway, and *Psammisotoma kingae*, which occurred inland from the littoral zone on some cays.

A species of more limited distribution appears to be cf. *Dicranocentrus* sp. nov. (Entomobryidae: Orchesellinae). This genus is not otherwise known to be marine littoral (but see later). Morphological characters indicate that it may belong to an undescribed genus. Individuals of probably the same undescribed genus have been collected from marine littoral habitats on Cocos and Keeling Islands as well as two already described species from the Philippines and Papua New Guinea (P. Greenslade unpublished results). A description of the new species, which appears at present to be restricted to the Great Barrier Reef Islands, is in preparation.

TABLE 4. Abundance of terrestrial Collembola families (No./m^2) of three cays of increasing degree of vegetation cover from the Swain Reefs.

Island	**Thomas**	**Bacchi**	**Gillett**
Family			
Isotomidae[1]	16 200	1 970	19 200
Tullbergiidae[2]	73		66
Hypogastruridae[3]	20	20	394 000
Brachystomellidae[4]	33	6 490	6 870
Total	**16 326**	**8 480**	**420 136**

[1] Included *Folsomina onychiurina* Denis, *Folsomides exiguus* Folsom, *Mucrosomia caeca* (Wahlgren), *Isotomodes* sp.

[2] Included *Mesaphorura yosii* Rusek *Tullbergia* sp.

[3] Included *Xenylla manusiensis* da Gama, *Ceratophysella denticulata* (Bagnall)

[4] Included *Brachystomella* spp.

TABLE 5. The abundance of *X.manusiensis* (No./m^2) and amount of organic matter (g/m^2) for three cays of the Swain Reefs.

	Thomas	**Bacchi**	**Gillett**
X.manusiensis	33	20	394 000
Organic matter	15	185	1 047

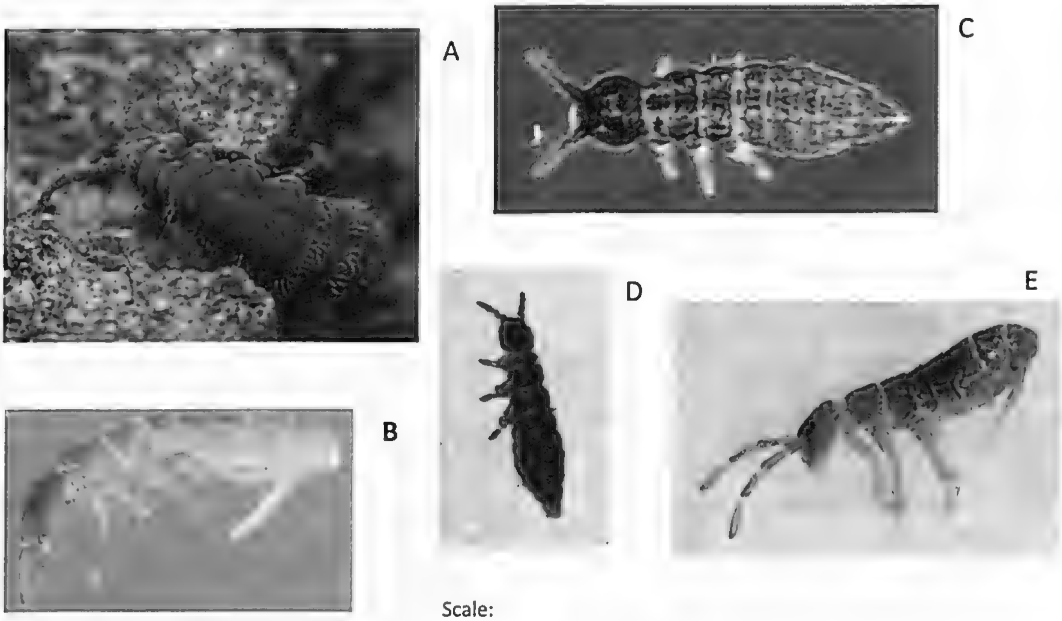

FIG. 3. Photographs of marine littoral Collembola genera similar to those found on Swain Reefs Cays. A, *Pseudanurida* sp. (© J. Kuh), B. *Archisotoma* sp. C, *Friesea* sp., D, *Xenylla* sp., E, *Axelsonia* sp. (photographs: B, A. Fjellberg; C, D, E, J. Forrest.)

MORPHOLOGICAL AND BEHAVIOURAL ADAPTATIONS TO LITTORAL LIFE

Observations of live animals on beaches and in the laboratory have revealed morphological features and behaviours that allow marine littoral Collembola to survive periodic and regular inundation with seawater. Retaining a bubble of air (plastron) beneath the body during inundation (*Pseudanurida, Xenylla*) and having a dense covering of short chaetae that protects against water logging (*Axelsonia, Archisotoma*) are two such morphological adaptations. A behavioural adaptation is to retreat under stones that have a concave under-surface or into cracks in rocks; both habitats are able to retain air bubbles within or under them at high tide (*Xenylla*, *Entomobrya*) (P. Greenslade, unpublished observations). Aggregations in such places may be facilitated by a pheromone (Manica et al. 2001) under the control of an intrinsic diurnal rhythm. *Archisotoma* species may even be able to live within a water film; they also have a dense covering of short chaetae. Although behavioural adaptations of marine littoral Collembola have been studied in the Northern Hemisphere (Witteveen & Joose, 1988 and included references), the species and even some genera differ so there is room for more studies in Australia on this topic.

FACTORS AFFECTING COLLEMBOLA OF GREAT BARRIER REEF ISLANDS

We found that there are several factors that influence the colonisation, composition and abundance of Collembola on these islands. Firstly, marine littoral species dominate the fauna of all but large well-vegetated islands and are likely to be primary colonisers. For instance, after the Krakatau eruption, the first species to colonise Anak Krakatau, the new island, were (along with spiders), marine littoral Collembola (Greenslade 2008a). Both taxa can be dispersed on the wind and on water, probably in floating plant debris (Gillespie et al., 2011, Hawes et al. 2007).

Food as well as habitat availability determine the successful survival and spread of species once they arrive; for example, marine littoral isotomids whose food base could be primarily of plant origin such as marine algae. Once nesting seabirds colonise a newly emerged island, the resources for invertebrates are more plentiful with guano providing nutrients for higher plant production and with additional organic matter provided by increasing plant biomass and dead birds. The abundant hypogastrurids on the vegetated islands probably feed on carrion and guano (Heatwole,

1971). Some could be prey for birds (Bengtson & Fjellberg, 1975) or fish (Chargulaf & Tibbetts, 2015).

Plant cover, which is determined by island age, size and incidence of recent cyclones, is obviously important for terrestrial species. Large vegetated cays possess more diverse habitats for Collembola. Within One Tree Island, Done (1976) found that high species richness was related to a greater heterogeneity of habitat for microarthropods. It has been suggested that these cays may undergo a cyclical change in the amount of vegetative cover present because of bird nesting activity with related denudation. They could also suffer destruction of vegetation by storm swells and cyclones. When this happens, terrestrial Collembola will also undergo similar cycles of extinction and recolonisation. The frequency of these extreme events is predicted to increase as well as current and future sea level rises putting the terrestrial and even marine littoral fauna at risk of extinction. In 2009, tropical cyclone Hamish, inundated some of the cays surveyed (Bacchi, Bell, Bylund and Gillett) and the vegetation has not recovered on these cays (DNPRSR 2013). Swain Reefs National Park and adjoining State Marine Park Management Statement 2013. In addition, climate warming may drive species southwards as shown by Pitt et al. (2010) in Tasmania.

At the time of sampling, total numbers of terrestrial Collembola on Gillett were higher than on One Tree Island and so was vegetation (Done 1976). Gillett is a sand cay while One Tree Island is a rubble cay, and soil microclimatic differences (e.g. in water holding capacity) could affect the distribution and abundance of Collembola on each island and was found elsewhere (Verhoef & van Selm, 1983). The dominance of hypogastrurid Collembola would be related to the amount and variety of organic detrital substrates along with a more diverse microflora. Further support for this comes from an examination of the relationship between cryptostigmatid mites and amount of organic matter. In the 1983 quantitative study of Thomas, Bacchi and Gillett cays where Collembola communities were examined, a similar association with organic matter to that of *X. manusiensis* was found for cryptostigmatid mites with the linear regression relationship being:

$\text{Log(No./m}^2) = 1.847 + 0.00144 \text{ (OM g/m}^2) \text{ R} = 0.650$.

The correlation coefficient was again significant ($P<0.001$). Cryptostigmatid mites are also known plant detritus feeders.

In 2007, Collembola populations were recorded as reduced on North East Herald Coral Cay (Figure 2) probably by an invasion, of the ant, *Tetramorium bicarinatum* (Nylander) around seven years earlier. The invasion was associated with a reduction in the abundance of other ground living invertebrates as well as death of *Pisonia grandis* R.Br. trees, so adversely affecting the protected sea bird populations (Greenslade, 2010). The ant was probably brought to the island in boxes of supplies from Cairns, including fresh fruits and vegetables.

CONSERVATION MANAGEMENT OPTIONS

There are currently no quarantine controls or inspections for any islands of the Great Barrier Reef despite considerable tourist visitation although Queensland Parks Service include them in their island management plans (Fitzroy Island). For practical reasons of resource limitation, quarantine inspections of all food, equipment, luggage and vessels would be impossible and a ban on fresh food unlikely to be acceptable. However, we suggest more effort should be made to inform visitors and commercial operations on the islands of the dangers of inadvertently introducing alien organisms, especially ants. When visitor permits are issued, it would be advisable for applicants to be provided with a set of guidelines as to what they should not take onto any island and how to inspect anything they do take for exotics. No doubt, resources would be too limiting to ensure compliance, but staff at resorts could be perhaps given a more comprehensive guide. As a model, the regulations and inspections of tourists and expeditioners visiting Antarctic and Subantarctic stations could be used (see Greenslade, 2002, Greenslade & Convey 2012).

ACKNOWLEDGEMENTS

The senior author thanks the Queensland Department of National Parks, Sport and Racing for access to Swain Reefs.

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RECOVERY OF REPTILE, AMPHIBIAN AND MAMMAL ASSEMBLAGES IN AUSTRALIAN POST-MINING LANDSCAPES FOLLOWING OPEN-CUT COAL MINING

HOUSTON, W. A.[1,2], MELZER, A.[2] AND BLACK, R. L.[1]

Amphibian, reptile and mammal assemblages were evaluated as bioindicators of mining rehabilitation recovery at three northern Australian coal mines. Ten rehabilitated blocks of three ages, early (up to 7 years, five sites), mid (8 to 15 years, four sites) and late (24 years, one site), were compared with 11 local unmined reference sites. Because mining in this region mostly alters the topography from rolling plains to hills, reference forest sites included vegetation typical both of the pre-mining landscape and local hill-associated landscapes analogous to post-mining topography. Habitat attributes showed consistent patterns with age, reflecting successional changes from the initial dense plantings. Species richness of reptiles, and of lizard functional groups, increased with rehabilitation age. Reptile species assemblage also showed a trend towards the composition of reference forest sites. In contrast, metrics for the other faunal groups rapidly attained levels comparable to the reference sites, or fluctuated greatly. Lizard functional groups showed patterns of recovery consistent with microhabitat development. 'Terrestrial' foraging lizards attained similar species richness to reference forest sites by mid-age rehabilitation whereas 'arboreal' and 'fossorial' lizard species were slower to colonise the rehabilitation. These findings complement studies from Australian bauxite and gold mining landscapes, suggesting that the utility of reptile assemblages as broadly applicable bioindicators should be considered.

Keywords: open-cut coal mining, functional group, guild, rehabilitation success indicators, revegetation, habitat restoration, chronosequence

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INTRODUCTION

Australian studies have found that while post-mining rehabilitated landscapes frequently achieved species richness measures comparable to nearby vegetation, achieving equivalent assemblage composition was more difficult, irrespective of the biota being evaluated (Brady and Noske, 2010; Cristescu et al., 2012; Gould, 2011). Typically, monitoring of rehabilitation progress has been based on the premise that as long as vegetation returns then fauna will follow, but this is a flawed assumption (Gould, 2011; Ruiz-Jaen and Aide, 2005). It is now recommended that rehabilitation evaluation should include fauna as well as flora (Cristescu et al., 2012; Cristescu et al., 2013; Majer, 2009; McDonald et al., 2016; Nichols and Grant, 2007).

Approaches to evaluating rehabilitation success range from a focus on individual "indicator" species to whole-of-assemblage approaches (Cristescu et al., 2012). Current thinking recognises that it is not feasible to include all faunal taxa and that a subset is the only practical approach. However, which subset to use has been contentious (Andersen, 1999; McGeoch, 1998). Many faunal groups have been proposed for monitoring post-mining rehabilitation including birds, terrestrial vertebrates, ants, spiders, springtails, bugs, grasshoppers and beetles among others (Andersen et al., 2004; Andersen et al., 2001; Greenslade and Majer, 1993; Majer et al., 2004; Nichols and Grant, 2007; Nichols and Nichols, 2003; Orabi et al., 2010; Stork and Eggleton, 1992).

In general, indicators should include taxa with functional relevance to ecosystem health, such as soil invertebrates, as well as assemblages of distant phylogenies, such as those that are representative of invertebrate and vertebrate fauna (Cristescu et al., 2012; Hilty and Merenlender, 2000; Nichols and Grant, 2007). Different faunal groups may provide information at different spatial scales (Thompson et al., 2008). For example, birds have been shown to be useful at the landscape level (Gould, 2011), while reptiles were found to be sensitive to habitat attributes that related to rehabilitation age (Thompson

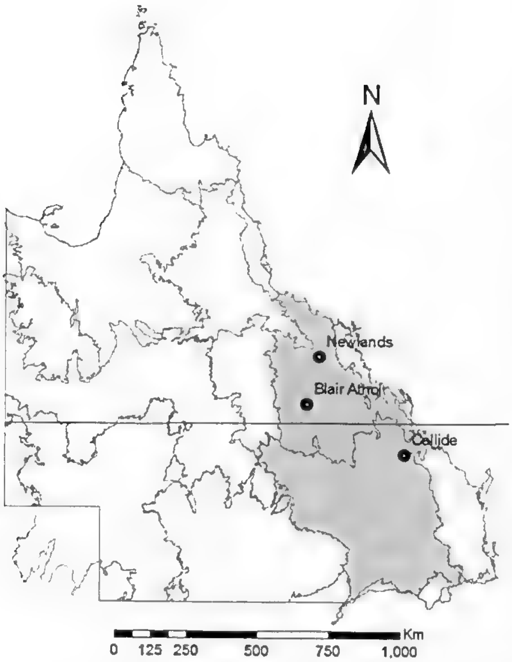


FIG. 1. Location of study sites. The grey area indicates the extent of the Brigalow Belt Bioregion in Queensland and the solid line the Tropic of Capricorn.

and Thompson, 2005; Thompson et al., 2008). In Australia, the usefulness of the 'guild' or functional group concept has been demonstrated in multispecies management situations in woodlands in agricultural landscapes (Eyre et al., 2015; Michael et al., 2015). Such an approach may also be applicable in post-mining rehabilitated landscapes. The relatively high species richness of reptile assemblages, their dependency on specific microhabitat features, and the range of niches occupied make them ideal candidates for investigating ecosystem recovery of rehabilitation (Kutt et al., 2012a; Thompson and Thompson, 2005; Thompson et al., 2008).

Central Queensland mines undertake specific studies of rehabilitation progress to meet particular regulatory requirements. Where comparable methods are applied, studies from multiple mines can be combined to garner greater knowledge of rehabilitation processes. Whilst such an approach is not as powerful as a more formally designed ecological experiment, the analysis of collected studies has the potential to increase knowledge of rehabilitation processes. Here we took three independent but comparable studies and constructed a pseudo-chronosequence to evaluate the pattern of colonisation of the post-mining landscape by terrestrial fauna. To achieve this we evaluated biodiversity metrics of three taxonomic groups (amphibians, reptiles, mammals) over a temporal sequence of mine rehabilitation in relation to local reference sites. Metrics evaluated included species richness, assemblage change over time and lizard functional groups. Data were derived from the datasets of three Central Queensland mines contained in two technical reports (Houston et al., 2005; Houston et al., 2003), and one thesis (Knight, 2002). The utility of these faunal groups as potential indicators of the evaluation of the post-mining landscape is discussed.

MATERIALS AND METHODS

STUDY AREA

Vertebrate assemblages were evaluated at three locations (Blair Athol, Newlands and Callide Coal mines) in the extensive woodlands of north-eastern Australia (Figure 1). Blair Athol was the most westerly, approximately 260 km from the coast (22° 40.846' S, 147° 31.877' E), the other two being approximately 135 km inland with Newlands the most northerly (21° 13.021' S, 147° 53.491'E) and Callide the most southerly (24° 19.584'S, 150° 37.938'E).

The study region spans the Tropic of Capricorn and has a warm, seasonally wet/dry climate that is typified by long, hot summers and mild winters (Hutchinson et al., 2005). Summers are wet with more than 50% of the rainfall falling between December and March.

All three locations are in the same biogeographic region, the Brigalow Belt (Sattler and Williams, 1999). Common vegetation types in the region are woodlands typically dominated by eucalypts (*Eucalyptus* or *Corymbia*) or wattles (*Acacia*). All three locations encompass plains and hills with a range of soil types, generally with more fertile soils associated with creek valleys.

Open cut coal mines in this region can be several 100 m deep, and mining typically results in an excess of overburden requiring rehabilitation. While each mine differs slightly in the rehabilitation procedure, generally it includes removal and stockpiling of topsoil prior to mining, forming the overburden to moderate slopes, returning topsoil, and seeding with a variety of grasses, shrubs and trees.

SITES

Ten rehabilitation and 11 unmined reference forest sites were selected from among the three coal mines (Table 1). The rehabilitation sites formed a pseudo-chronosequence with a range of ages post-revegetation: early (up to 7 years, five sites), mid (8 to 15 years, four sites) and late (one site only, 24 years). Rehabilitation protocols of the oldest site differed from the others in that topsoil was not returned following reshaping of the substrate. Sites are described in Table 2.

The collated reference sites represented forested sites across the range of local natural remnant vegetation (Table 2). This approach is consistent with the Society for Ecological Restoration recommendations that reference sites should be in the same life zone, close to the restoration project, and should be exposed to similar natural disturbances as the rehabilitation sites (SER, 2004). Disturbance associated with open cut mining includes removal of the original vegetation and associated fauna, and the loss of soil horizons. While top-soils can be removed and reapplied to the rehabilitated landscape, such major disturbance typically results in the creation of novel ecosystems with different soil horizons and chemical composition to that which existed previously, and often different topography (Doley and Audet, 2013; Williams et al., 2017). Importantly, this means that the end result of vegetation recovery to a stable, self-sustaining ecosystem cannot be predicted with certainty and is likely to be a blend of the range of existing vegetation types present (Doley and Audet, 2013; Vickers et al., 2012). In this study, as in other studies of this type, no single natural vegetation type is likely to represent the end point and so a range of vegetation types were selected for reference sites (Gould, 2011).

SAMPLING METHODS

To avoid edge effects, a central point at each site was selected for undertaking vertebrate fauna trapping and sampling. Each site comprised an area of approximately 3 ha, typically within a 100 m radius of the central location within the same habitat or, for linear habitats such as riparian vegetation, a narrow rectangular plot. Each site was surveyed over 10 days except for winter samples at Blair Athol which were over 7 days.

Survey techniques used at all sites were: (i) a 30 m drift fence incorporating five or six shaded 20 L buckets at regular intervals; (ii) Elliot A and Elliot B traps, baited with a mixture of peanut butter, rolled oats and pet jerky, and placed at 5 to 10 m intervals depending on the terrain; (iii) intensive day time searches for amphibians, reptiles and animal traces such as scats, tracks, skeletal remains, scratch marks on trees, burrows, defecation piles and carcasses, including searches under rocks, fallen bark and timber and raking through piles of leaf litter (2 person-hours at each site per season); (iv) intensive spotlight searches for nocturnal wildlife at each site including searches on the ground as well as lower trunks of trees, under fallen timber and scanning of trees for arboreal mammals and geckos (1 person-hour at each site per season). All traps were checked twice daily to avoid fauna losses.

Methods for Blair Athol differed slightly in that a site comprised the pooled data from two drift fences, one upper and one lower slope (Knight, 2002). Differences between Blair Athol and the other two sites are shown in Table 3. Total search effort by survey technique are also shown in this table. Although there were some differences in search effort between each location, sites within locations had the same sampling effort. Differences in search effort between locations were considered to be relatively minor in comparison to the broad overlap between them.

Field identifications were made by the survey team with reference to field guides (Barker et al., 1995; Cogger, 2014; Triggs, 2004; Van Dyck and Strahan, 2008). Where necessary, specimens were retained for confirmation of identification by the Queensland

TABLE 1. Site types by location.

Locations	Early sites	Mid sites	Late Sites	Reference
Blair Athol	2	1		4
Newlands	2	2		5
Callide	1	1	1	2
Total	5	4	1	11

TABLE 2. Site descriptions – vegetation, soils and landform morphological type (Speight, 1990).

The first site code letter indicates the location: B – Blair Athol, N – Newlands or C – Callide, the second whether a reference site (N) or a rehabilitation site (R) while the number associated with rehabilitation sites indicates years since establishment at the time of sampling

Location/Site Code	Site Stage	Vegetation description
Blair Athol		
Reference		
BNa	forest	Upper slopes with *Eucalyptus crebra* and *Acacia rhodoxylon* woodland with sparse, shrubby undergrowth; lower slopes with *E. tereticornis* and *E. melanophloia* open woodland with dense grassy undergrowth/lower to upper slopes
BNb	forest	Upper slopes with *Eucalyptus crebra* and *Acacia rhodoxylon* open woodland with sparse undergrowth; lower slopes with *E. populnea* open woodland with dense shrubby and grassy undergrowth/lower to upper slopes
BNc	forest	Upper slopes with *Eucalyptus crebra* and *Acacia* woodland with sparse undergrowth; lower slopes with E. melanophloia open woodland with dense undergrowth/lower to upper slopes
BNd	forest	Upper slopes with *Eucalyptus crebra*, *Acacia rhodoxylon* and *A. shirleyi* forest with sparse undergrowth; lower slopes with *Corymbia citriodora* woodland with dense undergrowth/lower to upper slopes
Rehabilitation		
BR1	early	Sparse to very sparse canopy with patchy undergrowth/lower to upper slopes
BR2	early	Sparse to moderate canopy with dense undergrowth/lower to upper slopes
BR13	mid	Open to mid-dense canopy with patchy to dense undergrowth/lower to upper slopes
Newlands		
Reference		
NNa	forest	Low forest of *Acacia harpophylla* over a sparse midstorey of *Eremophila* sp. and patchy ground cover of *Carissa ovata*, grasses and herbs on clay soils; gilgais present/mid slope
NNb	forest	Dense shrubland with emergent *Brachychiton* spp. and *Eucalyptus* spp. on well drained red soils/crest
NNc	forest	Tall open woodland of *Eucalyptus tereticornis*, *Casuarina cunninghamiana*, *Corymbia* spp. and *Melaleuca bracteata* with a midstorey of *Ficus* sp., *Cassia brewsteri*, *Melaleuca bracteata*, and *Santalum* sp. over a ground cover of *Carissa ovata* and tussock grasses on alluvial soils/creek flats
NNd	forest	*Eucalyptus orgadophylla* open woodland over a closed grassland on undulating black self-mulching clay soils/undulating plains
NNe	forest	*Eucalyptus crebra* open woodland over a sparse grassland on shallow red soils/low rises
Rehabilitation		
NR4	early	Low very open shrubland over a sparse to dense grassland/mid to upper slope
NR6	early	Low open *Corymbia/Eucalyptus* woodland to low shrubland with a sparse to dense *Acacia* spp., *Corymbia/Eucalyptus* and *Alphitonia excelsa* midstorey covering a sparse to dense grassland/mid to upper slope

Location/Site Code	Site Stage	Vegetation description
NR8	mid	Low open *Corymbia/Eucalyptus* woodland to low shrubland with a sparse to dense *Acacia* spp., *Corymbia/Eucalyptus* and *Alphitonia excelsa* midstorey covering a sparse to dense grassland/mid to upper slope
NR10	mid	Low open *Corymbia/Eucalyptus* woodland with a sparse to dense *Acacia* spp., *Corymbia/Eucalyptus* and *Alphitonia excelsa* midstorey covering a sparse to dense grassland/mid to upper slope
Callide		
Reference		
CNa	forest	*Eucalyptus decorticans* and *Acacia shirleyi* open forest with shrub midstorey and grassy groundcover on sandstone/upper slope
CNb	forest	*Eucalyptus crebra* and *Corymbia citriodora* open forest with shrub midstorey on sandstone/lower slope and creek flats
Rehabilitation		
CR5	early	*Corymbia citriodora* and *Acacia* spp. regrowth low forest/mid slope
CR14	mid	*Corymbia citriodora* and *Eucalyptus* sp. (ironbark) regrowth low forest/lower slope
CR24	late	*Corymbia citriodora* regrowth woodland with dense grassy groundcover/upper slope

Museum. To verify field identifications, hair samples of captured mammals and from scats were analysed by a mammal expert (B. Triggs), and skeletal remains by the Queensland Museum.

Two seasons were sampled at each location– wet (or late wet depending on the weather and site access) and dry: Blair Athol (22nd February to 3rd March 1997 and 5th July to 11th July 1997); Newlands (12th to 21st March 2003 and 19th to 28th June 2002); and Callide (6th to 15th April 2005 and 14th to 23rd August 2005). The data from these two seasons were pooled to form one dataset.

HABITAT STRUCTURE

Habitat data were collected at each site from two of the three locations (Callide and Newlands) and were used to examine changes in habitat structure with stand age in relation to the remnant forest vegetation. At two points, 50 m apart at each trap-site, percentage ground cover of tussock grass, litter and logs were visually estimated within a 10 m radius of each point. Within this diameter, the number of dead saplings (< 10 cm diameter) and trees (> 10 cm diameter) with exfoliating bark were also counted. The basal area of trees with hollows in two size classes (hollows less than 10 cm and hollows greater than 10 cm) was estimated using a basal area wedge.

LIZARD FUNCTIONAL GROUP CLASSIFICATION

A guild generally refers to groups of organisms using a common resource (Michael et al., 2015). However, in this study, such data were lacking so lizard species were grouped on the basis of their foraging habits, and sheltering requirements. This classification was based on expert knowledge of the research team, and details in field guides listed earlier. Foraging habits were: (i) terrestrial – those typically foraging on the soil surface; (ii) arboreal – those primarily living on trees, and (iii) fossorial – those with burrowing habits or semi-fossorial fauna associated with large woody debris or rock slabs, presumably for protection from predation. Lizards found perching in low bushes or on timber (e.g. *Pogona barbata*) but foraging predominantly on the ground surface were classified as terrestrial foragers. The three groups in this study are, for convenience, referred to as 'functional groups' (Eyre et al., 2015) and broadly resemble the microhabitat associations defined for temperate woodlands of southern Australia (Michael et al., 2015) and the habitat preferences used by Thompson and Thompson (2008).

To examine the influence of location and site type on lizard functional groups, the species richness values of each group (terrestrial, arboreal and fossorial) at a site were standardised by expressing

TABLE 3. Sample methods used at each trapping site and total effort.

Location/ Sample method	Number of sub-sites	Duration	Trap Number	Effort/season	Number of seasons*	Total Effort (both seasons)
Blair Athol						
Drift-fence (30 m length with 5 buckets)	2	10 days	5	100 bucket-days	1 (Summer)	170 bucket-days
Drift-fence (30 m length with 5 buckets)	2	7 days	5	70 bucket-days	1 (Winter)	
Elliott size A mammal traps	2	5 days	6	60 trap-nights	2	120 trap-nights
Elliott size B mammal traps	2	5 days	1	10 trap-nights	2	20 trap-nights
Cage trap	2	6 days	2	20 trap-nights	2	40 trap-nights
Intensive day searches	2			1 person-hour	2	4 person-hours
Intensive night searches	2			1/2 person-hour	2	2 person-hours
Newlands						
Drift-fence (30 m length with 6 buckets)	1	10 days	5	50 bucket-days	2	100 bucket-days
Elliott size A mammal traps	1	10 days	16	160 trap-nights	2	320 trap-nights
Elliott size B mammal traps	1	10 days	1	10 trap-nights	2	20 trap-nights
Cage trap	1	10 days	1	10 trap-nights	2	20 trap-nights
Intensive day searches	1			2 person-hours	2	4 person-hours
Intensive night searches	1			1 person-hour	2	2 person-hours
Callide						
Drift-fence (30 m length with 6 buckets)	1	10 days	6	60 bucket-days	2	120 bucket-days
Elliott size A mammal traps	1	10 days	23	230 trap-nights	2	460 trap-nights
Elliott size B mammal traps	1	10 days	2	20 trap-nights	2	40 trap-nights
Intensive day searches	1			2 person-hours	2	4 person-hours
Intensive night searches	1			1 person-hour	2	2 person-hours
* summer and winter						

them as a percentage of the total functional group species richness at that location (Callide, Newlands or Blair Athol). Although not ideal for statistical analysis, this was necessary due to the substantial difference between locations in species richness of certain functional groups. Terrestrial species may be regarded as 'generalists' while arboreal and fossorial species may be regarded as having 'specialist' habitat requirements (Thompson and Thompson, 2007).

DATA ANALYSIS

For each faunal group (amphibian, reptile and mammal), two hypotheses were tested in this study: first that species richness increases with rehabilitation age; and second that faunal assemblages become more similar to the reference forest sites. For reptiles, the known foraging preferences of lizards were used to evaluate a third hypothesis that species with specialist habitat requirements are slower to colonise than species with more generalist requirements.

Analysis of variance (ANOVA) was used to evaluate the influence of age since establishment on amphibian, reptile and mammal species colonisation of rehabilitation sites (i.e. species richness) based on a two-factor model: location (Blair Athol, Newlands or Callide) by site type (early, mid-age rehabilitation and forest) (Quinn and Keough, 2002). *A posteriori* Tukey tests (multiple pairwise comparisons) were used to identify significant differences between treatment groups (location or site type if significant). The same approach was used to analyse the lizard functional group data. However, where assumptions of ANOVA were not met, a non-parametric equivalent, the Kruskal-Wallis test was used.

Patterns of colonisation of rehabilitation sites over time by amphibian, reptile and mammal assemblages were evaluated based on presence-absence data using PRIMER-E version 7. The data were compared to the reference forest sites using a Bray-Curtis similarity index (Clarke and Warwick, 2001). Non-metric multidimensional scaling (nMDS) was performed on the Bray–Curtis matrix (50 restarts) to produce ordinations of similarity. Analyses of similarities (ANOSIM) (Clarke, 1993) tested for significant differences in faunal species composition based on location and site type (early, mid-age rehabilitation and forest). '*R*-statistics were considered significant at $P < 0.05$. Post-hoc tests were applied where appropriate.

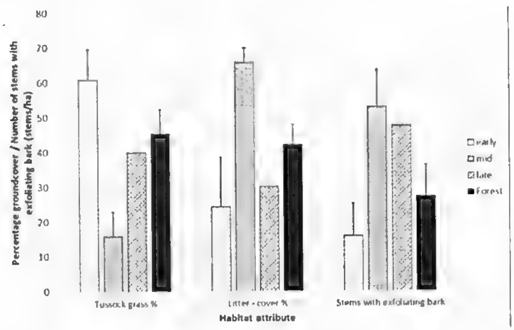


FIG. 2. Comparison of habitat attributes of rehabilitation (early, mid and late) with reference forest sites (± SE): Tussock grass % cover, litter % cover and stems with exoliating bark (stems/ha).

Because there was only one site at one location of that age, data for the late-age site were presented graphically but were not included in the statistical analyses.

RESULTS

HABITAT STRUCTURE

Groundcover of early-age rehabilitation was dominated by tussock grasses. This cover declined in mid-age rehabilitation following growth of saplings (Figure 2). Consistent with this was the dominance of the groundcover by leaf litter, rather than grass, in mid-age rehabilitation. A more even spread of tussock grass and litter was observed in the single example of a late-age rehabilitation site and it more closely resembled the groundcover mix of the reference forest sites. Development of arboreal habitat was apparent in mid and late-age rehabilitation, with the death of saplings and small trees leading to development of exfoliating bark habitat for arboreal fauna such as geckos and fence skinks (Figure 2). Only the late-age rehabilitation site developed tree hollows. The basal area of trees with small hollows at this site was 0.5 m^2/ha compared with 1.4 m^2/ha ± 0.4 (s.e.) for reference forests. However, important habitat attributes for cryptic fauna such as logs were not found in any of the rehabilitation sites whereas log cover averaged 5.4% ± 2.0 at reference forest sites.

TRENDS IN SPECIES RICHNESS

Reference forest sites scored higher fauna species richness than rehabilitation sites, up to 39 at Callide (Table 4). The relatively low count of 13 species at one Newland reference site was an outlier, (but

typical of other low complexity habitats in the region; Houston and Melzer, unpublished data), with all other Newlands reference sites having 22 or more species. Rehabilitation sites generally had lower species richness than the reference forest sites (Table 4), but some had up to 25 species.

Both amphibian and mammal species richness differed significantly by location (ANOVA: $F_{2,11}=17.607$, $P<0.001$ $F_{2,11}=5.789$, $P<0.050$ respectively), but reptiles did not ($F_{2,11}=3.714$, $P>0.050$) (Figure 3a). Blair Athol had more amphibian species but less mammal species than the other sites (Tukey tests, $P<0.050$).

Only reptile species richness differed significantly by site type (ANOVA: $F_{2,11}=38.254$, $P<0.001$) (Figure 3b) but there was also a significant interaction term (ANOVA: location x site type: $F_{4,11}=6.059$, $P<0.010$). This interaction was due to the relatively greater species richness of the reference forest sites at Callide compared to reference sites at the other two locations (Tukey tests, $P<0.050$); whereas each of the two age classes of rehabilitation sites (early and mid) had similar levels of species richness at all three locations (Tukey tests, $P>0.050$). Comparing site types, species richness of reptiles showed a steady increase through the chronosequence, with species richness in the mid-age class significantly greater than the early class, and reference forest significantly greater than the mid-age class (Tukey tests, $P<0.050$). At the mid-point of mid-age rehabilitation, 12 years post-establishment, reptile species richness had attained approximately two-thirds of the average species richness of the reference forest sites.

Total species richness (combined amphibian, reptile and mammal) did not differ by location, but did differ by site type (location: $F_{2,11}=2.120$, $P>0.050$, site type: $F_{2,11}=12.060$, $P<.010$, location x site type: $F_{4,11}=1.995$, $P>0.050$). Early rehabilitation differed significantly from reference forest sites (Tukey test, $P<0.010$) but the mid-age class did not, nor did they differ significantly from each other (Tukey test, $P>0.050$).

TRENDS IN FAUNAL COMPOSITION

All three assemblages (amphibian, reptile and mammal) varied significantly by location but only the reptile composition differed significantly between the reference forest sites and the rehabilitation age classes (Figure 4, Table 5). Reptile composition of the early-age rehabilitation differed significantly from the reference forest sites, but not from the mid-age rehabilitation. However, the trajectory of reptile composition trended towards that of the forest, youngest sites being most distant from the forest sites, and mid and late-age sites closer to the forest sites (Figure 4b). At the mid-point of mid-age rehabilitation, 12 years post-establishment, averaging the similarity of the four mid-aged rehabilitation sites to their respective reference sites and comparing it to the average of the similarity of the respective reference sites to each other, showed that the reptile species assemblage was approximately 70% of the average similarity level shown by reference forest sites to each other.

LIZARD FUNCTIONAL GROUPS

The pattern of colonisation of rehabilitation sites by lizard functional groups was relatively consistent at all three locations. Terrestrial species colonised relatively rapidly while the arboreal and fossorial (i.e. combined large debris and fossorial) groups were much slower (Figure 5). The general pattern is for an increase in functional group species richness with rehabilitation age, although less evident in the functional groups with fewer species. It is interesting to note that the only non-topsoiled site (the late-age site) did not support any fossorial lizards.

With pooled data from the three locations, both terrestrial and arboreal species richness of lizard

TABLE 4. A comparison of cumulative species richness of amphibians, reptiles and mammals for reference sites and rehabilitation sites at the 3 locations.

Location	Reference sites	Rehabilitation sites
Callide	34 to 39	16 to 25
Newlands	13 to 30	15 to 17
Blair Athol	18 to 26	11 to 19

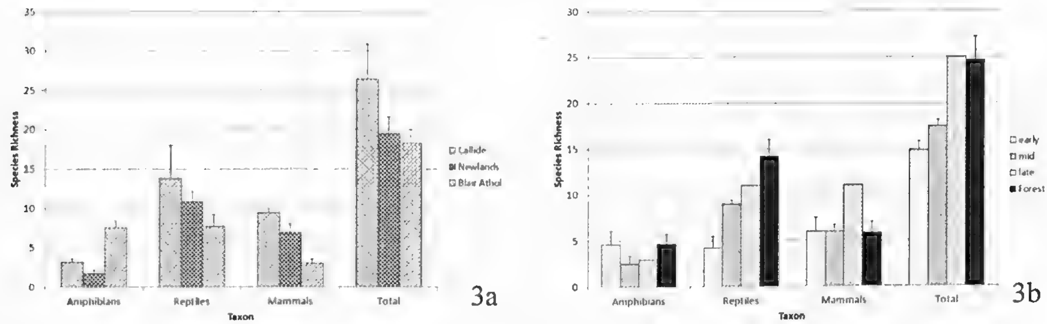


FIG. 3. Change in mean species richness (± SE) of the amphibian, reptile and mammal taxa with A. location (Callide, Newlands, Blair Athol) and B. site type (early, mid, late or reference forest).

functional groups differed significantly by site type (Kruskal-Wallis test: H_2 =11.045, P<0.01, n=20; H_2 =11.543, P<0.01, n=20 respectively), while the fossorial functional group did not (H_2 =2.613, P>0.05, n=20). Early-age rehabilitation had significantly fewer terrestrial and arboreal lizard species than the forest vegetation (Multiple Comparisons tests: z'=3.239, P<0.01, N=20; z'=3.077, P<0.01, N=20 respectively), whereas mid-age rehabilitation, although lower, did not differ significantly from the reference forest sites.

DISCUSSION

HABITAT

The patterns in habitat structure shown by early, mid and late-age rehabilitation are consistent with a transformation from a tussock grass dominated community in the early-age rehabilitation, to a dense, sapling dominated plant community in the mid-age rehabilitation; the mid-age overstorey shading out the grass cover as well as providing a rich source of leaf litter (Bradley et al., 2010). This pattern is consistent with successional processes observed in natural woodlands in the region where resource competition has caused thinning of dense stands of regrowth pioneer species (Johnson et al., 2016).

SPECIES RICHNESS AND ASSEMBLAGE

Mid-age rehabilitation (i.e. age 8 to 15 years) generally had greater reptile diversity (species richness and assemblage composition) than early-age rehabilitation (i.e. age 1 to 7 years) but less than the reference forest sites. At the assemblage level, reptile species composition appeared to plateau in this middle period, indicating a longer time sequence is needed to evaluate progression to the next level. Similar patterns were observed in reptiles associated with bauxite mine rehabilitation

TABLE 5. R-statistics and significance levels of pair-wise differences in two-way ANOSIM on (a) Location and (b) Site Type for each vertebrate assemblage (amphibian, reptile and mammal). *=P<0.05, **=P<0.01, ***=P<0.001

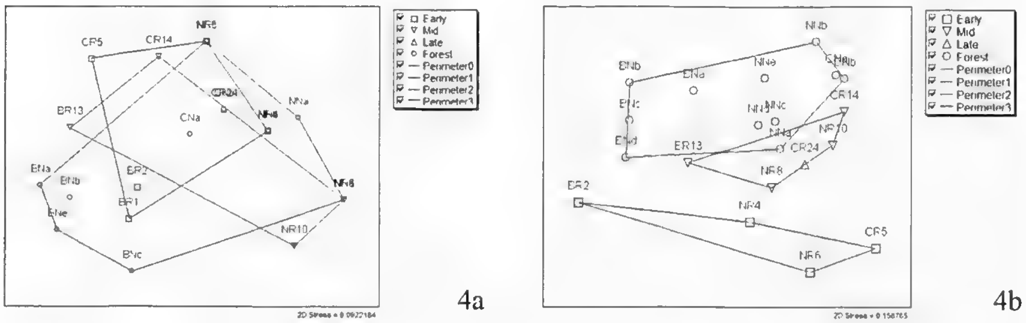
Location	Ambhibian	Reptile	Mammal
	Global r = 0.676***	Global r = 0.821***	Global r = 0.737***
Callide, Newlands	0.185	0.532*	0.294
Callide, Blair Athol	1.000*	1.000	1.000*
Newlands, Blair Athol	0.821**	0.879***	0.892**
Site Type	**Amphibian**	**Reptile**	**Mammal**
	Global r = 0.245	Global r = 0.384**	Global r = -0.009
Forest, Early	na	0.531*	na
Forest, Mid	na	0.290	na
Early, Mid	na	-0.250	na

(Craig et al., 2012; Nichols and Nichols, 2003). This most likely reflects the lack of additional habitat features such as accretion of deep leaf litter, friable soil and large woody debris (Craig et al., 2012; Eyre et al., 2015). In mining rehabilitation, such habitat features are known to take a much longer time to develop than other microhabitat features (Craig et al., 2012; Nichols and Nichols, 2003). Logs and large woody debris were almost totally absent in rehabilitation sites in this study, including the oldest site. Thus, to fully evaluate rehabilitation progress, monitoring needs to be undertaken over appropriate time frames consistent with development of such habitat attributes.

FUNCTIONAL GROUPS

The lizard functional group data showed coherence with vegetation structure. Terrestrial species colonised first, coinciding with the availability of grass tussocks and leaf litter, followed by arboreal species. The accrual of arboreal species such as geckos and fence skinks, coincided with the senescence of pioneer plants such as *Acacia* species in mid to late-age rehabilitation, providing microhabitat (exfoliating bark) for this functional group. These findings support the hypothesis that species with generalist habits will colonise successfully first followed by species with more specialist habits such as arboreal species requiring exfoliating bark or hollows and fossorial species with specialist microhabitat or dietary requirements. This concurs with other studies (Shoo et al., 2014; Thompson and Thompson, 2007).

Lizard functional groups offer a method of evaluating rehabilitation progress at a fine scale. Several studies have noted that fauna requiring complex shelter, such as large woody debris, are slower to colonise than other species (Craig et al., 2012; Kanowski et al., 2006; Nichols and Grant,



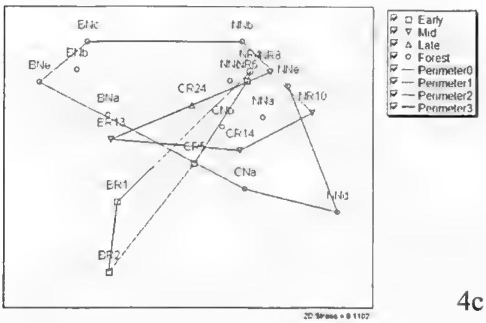


FIG. 4. Ordination (nMDS) of A. amphibian, B. reptile (BR1 not shown as no reptiles found) and C. mammal based on presence/absence transformed data for rehabilitation and forest sites; lines denote group boundaries (Henderson and Seaby, 2007).

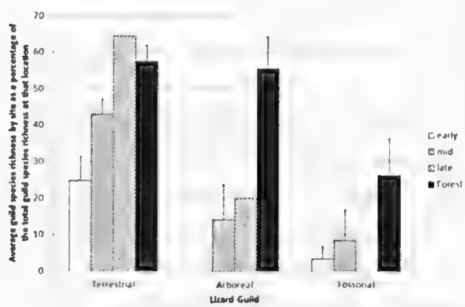


FIG. 5. Mean site species richness (± SE) by functional group (terrestrial, arboreal or fossorial) for each site type (early, mid, late or reference forest) expressed as a percentage of the total species richness in that functional group at each location.

2007). Incorporating lizard functional groups into the study provides another layer of information upon which to evaluate progress of rehabilitation.

EVALUATION OF BIOINDICATORS

Of the three taxa examined in this study, only reptiles had a timeline of faunal colonisation that was consistent with the chronosequence of increasing rehabilitation age, suggesting that reptiles may be a useful indicator of rehabilitation progress. Several reptile assemblage metrics increased with age when calibrated against nearby reference sites, including reptile species richness and reptile assemblage, as well as the species richness of lizard functional groups.

Reptiles were also relatively species-rich compared to other taxa surveyed in this study with a mean site species richness of 34 ± 1 compared to 11 ± 1 and 20 ± 1 respectively for amphibians and mammals. More species provides greater spread and discriminatory power, as well as a greater number of niches occupied, making reptiles more useful as a bioindicator group. Studies of other mine types and landscapes in Australia have reported similar findings including bauxite (Craig et al., 2012; Nichols and Nichols, 2003) and gold and nickel mines (Thompson and Thompson, 2005; Thompson et al., 2008).

Other groups have ecological attributes that detract from their value as bioindicators of rehabilitation progress. In general, birds, mammals and amphibians have greater dispersive capability than reptiles, and undergo substantial population fluctuations reflecting their greater dependence on seasonal rain for stimulating breeding (Kutt et al., 2012b; Letnic et al., 2004). An example of this was observed in this study. Blair Athol had significantly greater amphibian species richness than the other locations reflecting concurrence of the fieldwork with rainfall, and inundation of temporary frog breeding habitats (Knight, 2002). Such fluctuations can confound attempts to measure ecosystem responses of vertebrate fauna to other factors such as grazing (Kutt et al., 2012b; Read, 2002).

Mobile groups such as mammals and birds tend to have relatively larger home ranges, or be transient rather than resident species (Dickman et al., 1995; Thompson and Thompson, 2005). This means they tend to be associated with a greater landscape scale than the plot-sized areas subject to rehabilitation; causing uncertainty as to whether they are resident in the rehabilitation or moving through the local landscape.

One of the sites evaluated in this study (the mid-age Callide rehabilitation, CR14) was part of a study by Andersen et al. (2003). These authors identified this site as an example of successful restoration based on convergence of ant community composition with reference sites. In contrast, our study showed this site was intermediate in reptile species composition between the early rehabilitation and the reference forest sites. This was consistent with habitat structure; site CR14 appeared to be in a transitional phase with a dense stand of eucalypt saplings, little tussock grass cover and dense litter cover. This demonstrates the importance of recommendations that bioindicators be drawn from two or more indicators with distant phylogenies (Cristescu et al., 2012; Hilty and Merenlender, 2000) to allow for differences in habitat requirements and food availability at different scales of landscape complexity.

CONCLUSION

In summary, of the three hypotheses examined, only the timeline of the reptile assemblage was consistent with the chronosequence of rehabilitation age. After 12 years, the reptile species assemblage had approximately two-thirds of the average reptile species richness of the reference forest sites and was 70% of the average similarity level shown by reference forest sites to each other. Lizard functional group analysis supported the hypothesis that species with specialist foraging habits are slower to colonise than species with more generalist requirements. Further, the concurrence of findings from three distinct landscapes and contrasting mine types (bauxite, gold and nickel, and coal) suggests that the broad utility of reptiles as a bioindicator of rehabilitation progress is worthy of further investigation. Incorporation of reptile assemblages into rehabilitation monitoring programmes, and extending evaluation over appropriate time frames are recommended. A note of caution, however, a recent study of bauxite mines in southwestern Australia did not show convergence of reptile assemblages with those of reference sites, even after 20 years post-mining (Triska et al., 2016). Of relevance to future research, was the finding in this study that comparable independent studies can be analysed to inform principles in Central Queensland coal mine rehabilitation success.

ACKNOWLEDGEMENTS

Funding for technical studies was provided by Anglo Coal (Callide Management) and Newlands Coal. Fauna surveys were conducted under Queensland Government Scientific Purposes Permits C6/0075/00/SAA and WITK01501003 and Central Queensland University Animal Ethics Permit A02/04-131.

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APPENDIX 1. List of lizard species, functional group by location and occurrence in treatments; species and common names from Cogger (2014).

Functional Group: T=terrestrial; T*=terrestrial but perch in shrubs or on stumps; A=arboreal; F=fossorial (burrowing species); F*=fossorial (semi-fossorial species associated with large debris such as logs or rock slabs). Information based on expert experience of the survey team and Cogger (2014). Treatment: N=natural, RL=rehabilitation late, RM=rehabilitation mid, RE=rehabilitation early.

Species name	Common name	Functional Gr.	Callide	Newlands	Blair Athol	Treatment
Geckoes						
Diplodactylus conspicillatus	Fat-tailed Gecko	T			T	N
Diplodactylus vittatus	Wood Gecko	T	T	T	T	N, RM
Gehyra catenata	Chain-backed Dtella	A		A		N
Gehyra dubia	Dubious Dtella	A	A	A	A	N, RL, RM
Heteronotia binoei	Bynoe's Prickly Gecko	T	T	T	T	N, RM, RE
Lucasium steindachneri	Box-patterned Gecko	T			T	N
Nebulifera robusta	Robust Velvet Gecko	A	A			N
Nephrurus asper	Rough Knob-tailed Gecko	F*			F*	N
Oedura monilis	Ocellated Velvet Gecko	A	A	A		N
Oedura tryoni	Southern Spotted Velvet Gecko	F*	F*			N
Strophurus taenicauda	Golden-tailed Gecko	A	A			N, RM
Strophurus williamsi	Eastern Spiny-tailed Gecko	A		A		N
Underwoodisaurus milii	Thick-tailed Gecko	F*	F*			N
Snake-lizards						
Delma tincta	Excitable Delma	F*		F*		N, RM, RE
Lialis burtonis	Burton's Snake-lizard	T	T	T	T	N, RE
Paradelma orientalis	Brigalow Scaly-foot	F*	F*	F*		N
Pygopus schraderi	Eastern Hooded Scaly-foot	F*		F*		N

APPENDIX 1. (cont.) List of lizard species, functional group by location and occurrence in treatments; species and common names from Cogger (2014).

Functional Group: T=terrestrial; T*=terrestrial but perch in shrubs or on stumps; A=arboreal; F=fossorial (burrowing species); F*=fossorial (semi-fossorial species associated with large debris such as logs or rock slabs). Information based on expert experience of the survey team and Cogger (2014). Treatment: N=natural, RL=rehabilitation late, RM=rehabilitation mid, RE=rehabilitation early.

Species name	Common name	Functional Gr.	Callide	Newlands	Blair Athol	Treatment
Skinks						
Anomalopus brevicollis	Short-necked Worm Skink	F	F	F		N, RM
Carlia munda	Shaded-litter Rainbow-skink	T		T		N
Carlia pectoralis	Open-litter Rainbow-skink	T	T	T	T	N, RL, RM
Carlia schmeltzii	Robust Rainbow-skink	T	T	T		N, RL, RM, RE
Carlia vivax	Tussock Rainbow-skink	T			T	N, RM
Concinnia brachysoma	Northern Bar-sided Skink	F*	F*			N
Concinnia martini	Dark Bar-sided Skink	F*	F*			N
Cryptoblepharus pannosus	Ragged Snake-eyed Skink	A		A	A	N
Cryptoblepharus pulcher	Fence Skink	A	A			N
Ctenotus ingrami	Unspotted Yellow-sided Ctenotus	T			T	N, RE
Ctenotus robustus	Robust Ctenotus	T	T	T	T	N, RL, RM, RE
Ctenotus strauchii	Eastern Barred Wedgesnout Ctenotus	T		T		N
Ctenotus taeniolatus	Copper-tailed Skink	T	T	T		N, RM
Glaphyromorphus punctulatus	Fine-spotted Mulch-skink	F		F		N
Lerista fragilis	Eastern Mulch Slider	F	F	F	F	N
Lygisaurus foliorum	Tree-base Litter-skink	T	T	T	T	N, RL, RM, RE
Menetia greyii	Common Dwarf Skink	T	T	T	T	N, RL, RM, RE
Menetia timlowi	Dwarf Litter-skink	T	T	T		R, RL, RM
Morethia boulengeri	South-eastern Morethia Skink	T			T	N, RE
Morethia taeniopleura	Fire-tailed Skink	T	T	T		N, RL, RM, RE

Species name	Common name	Functional Gr.	Callide	Newlands	Blair Athol	Treatment
Dragon-lizards						
Diporiphora australis	Tommy Roundhead Dragon	T*	T	T		N, RL, RM, RE
Pogona barbata	Eastern Bearded Dragon	T*	T	T	T	N, RM, RE
Goannas						
Varanus gouldii	Gould's Goanna	T	T			N, RL
Varanus sp.	a goanna	T			T	N
Varanus tristis	Black-headed Monitor	A		A		N
Total species		**42**	**26**	**27**	**18**	
Functional Group						
Terrestrial		**22**	**14**	**15**	**14**	
Arboreal		**9**	**5**	**6**	**2**	
Fossorial		**11**	**7**	**6**	**2**	

BOX MISTLETOE (*AMYEMA MIQUELII*) DISTRIBUTION IS BIASED TOWARDS NORTHERN AND RIVER-FACING POSITIONS WITHIN THE CROWN OF URBAN GUM TREES

HUME, M. D.[12] & SCHMIDT, D. J.[1]

Population dynamics of epiphytic hemi-parasitic plants are excellent examples of how complex ecological relationships (host, parasite, disperser) influence the spatial distribution pattern of species. While the spatial distribution of mistletoe has been studied at landscape scales, less research has focused on patterns occurring within individual host trees which may be colonised by multiple mistletoes. Here we investigate the spatial distribution of *Amyema miquelii* (Loranthaceae) within the crown of gum trees *Eucalyptus tereticornis* (Myrtaceae) in urban parkland along the Brisbane River in southeast Queensland. Gums with and without *A. miquelii*, were surveyed by measuring DBH, tree height and crown diameter to assess the influence of host size on the presence and abundance of mistletoe. Within-host distribution of *A. miquelii* was examined by dividing the crown of host trees into four quadrants based on aspect (north, south, east and west). Quadrants facing the river and built environment were noted to investigate if the position of *A. miquelii* was influenced by proximity to the river or urban development in addition to aspect. Results of statistical analysis revealed that within 133 *E. tereticornis*, *A. miquelii* was spatially aggregated and in highest densities in large *E. tereticornis*. Mistletoe occurred significantly more on the riverside of the crown and in significantly higher densities in the northern quadrant of the host tree. We speculate on possible causes for the observed patterns of intra-host mistletoe distribution, particularly in relation to behaviour of the Australian mistletoebird (*Dicaeum hirundinaceum*) in urban environments. This study furthers our understanding of intra-host distribution of mistletoe, provides information relevant to managing mistletoe infections, and raises questions regarding the influence of urbanisation on foraging behaviour of the Australian mistletoebird.

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INTRODUCTION

Understanding processes that underpin distribution patterns is an important area of population ecology. Population dynamics of epiphytic hemi-parasitic plants, such as mistletoe species, provide an interesting focus of study in this area as spatial distribution patterns are closely linked to biotic factors (host species distribution and disperser behaviour) and abiotic factors such as light availability (Ward, 2005; Ward & Paton, 2007; Rawsthorne et al., 2012; Taylor & Burns, 2017). While different mistletoe species have been studied at a landscape scale, less research has examined within host tree distributions, with the focus primarily on vertical patterns. These studies have found evidence for spatial aggregation of mistletoe in the upper canopy due to increased light availability and perch preferences of bird dispersers (Shaw & Weiss, 2000; Aukema & Martinez del Rio, 2002).

Studies have consistently found mistletoe density rates increase in host trees with existing infections and are greatest in larger trees (Lavorel et al., 1999; Aukema & Martinez del Rio, 2002; Sayad et al., 2017). This pattern is strongly influenced by the attraction of bird dispersers to trees with established mistletoe plants in fruit and the short gut passage time of mistletoe seeds (Murphy et al., 1993; Aukema & Martinez del Rio, 2002; Rawsthorne et al., 2012). This can result in high densities of mistletoe, which due to its parasitic nature, may have a negative impact on the health of the host tree (Reid et al., 1994; Ramón et al., 2016). Consequently, studies have examined the removal of mistletoe to preserve host tree health (Maffei et al., 2016). However, the removal of mistletoe has been shown to have a negative impact on biodiversity, as mistletoe provides key resources for a range of birds, insects and small mammals (Watson, 2001, 2002; Watson &

Herring, 2012). Although several studies have considered this issue in the context of monoculture tree plantations and managed forests (Sreekar et al., 2016; Turner & Smith, 2016), no one has studied this issue in the context of managing trees in urban parkland. This makes our study particularly relevant as local councils and other government bodies have established guidelines for the removal of mistletoe, primarily *Amyema miquelii* (Loranthaceae) (Native Vegetation and Biodiversity Management Unit, 2013).

A. miquelii is an Australian native mistletoe which parasitises *Eucalyptus* spp. (Watson, 2011). It is primarily dispersed by the Australian mistletoebird (*Dicaeum hirundinaceum*) which feeds on the fleshy fruit produced by the plant (Reid, 1991; Watson, 2002; Ward, 2005). *A. miquelii* is common in urban parkland along the Brisbane River where it is utilised as a host plant for numerous butterfly species (Schmidt & Rice, 2002). Understanding how abiotic and biotic factors influence mistletoe distribution is essential in developing an informed management strategy that balances host tree health with the role of *A. miquelii* as a keystone species (Ward, 2005; Ward & Paton, 2007). Against this backdrop, the overall aim of this study was to investigate the spatial distribution of *A. miquelii*, within the crown of *Eucalyptus tereticornis* (Myrtaceae) in urban parkland within the riparian zone of the Brisbane River; and examine what factors may influence the distribution pattern. Specifically, this study addressed four questions:

1. Is *A. miquelii* aggregated within the crown of *E. tereticornis*?
2. Does the size of *E. tereticornis* influence the presence and density of *A. miquelii*?
3. Is the position of *A. miquelii* within the crown of *E.tereticornis* influenced by proximity to the river or urban development?
4. Is the position of *A. miquelii* within the crown of *E. tereticornis* influenced by aspect?

We hypothesised that *A. miquelii* would be spatially aggregated, and at greatest density in large *E. tereticornis,* both due to the foraging behaviour of the Australian mistletoebird and increased surface area within larger trees on which mistletoe can germinate. Further, in the context of urban parkland, we hypothesised that *A. miquelii* would be positioned in areas of the crown that were most sheltered from urban development due to the behaviour of the mistletoebird. Finally, we anticipated *A. miquelii* would occur at higher rates on an aspect most favourable to light availability.

METHODS

STUDY SITES AND DESIGN

The study area was located in Brisbane (centred on 27°33'07.8"S, 153°03'23.3"E). Brisbane is the capital of Queensland and Australia's third largest city. It experiences a subtropical climate with mean temperatures ranging from 11 to 21°C during winter months (June-August) and 21 to 30°C during summer months (December–February) (Bureau of Meteorology 2016). Average yearly rainfall is 1158mm with most precipitation falling in the summer months (Bureau of Meteorology 2016).

The study sites were fourteen riverside parks in the southern and western suburbs of Brisbane. These riverside parks were chosen as they were immediately adjacent to residential or commercial development (Appendix A). All riverside parks were open for community use as recreational green space and managed by the Brisbane City Council.

Only *E. tereticornis* located in the riparian zone of the Brisbane River within these study sites were included in the study.

DATA COLLECTION

During April 2017, the diameter at breast height (DBH) (cm), height of tree (m) and crown diameter (m) were recorded for all *E. tereticornis* observed to be hosting *A. miquelii* from the ground and selected *E. tereticornis* not hosting *A. miquelii*. Trees not hosting mistletoe were selected based on proximity to host trees (nearest neighbour) ensuring no preference was given to a size of tree. Trees which were observed to have signs of obvious pruning were not surveyed. For the purposes of this study, tree crowns were assumed to take the shape approximate to a sphere (Sayad et al., 2017). Crown diameter was defined as the distance between the base of the lowest branch and the top of the crown and measured to the closest metre.

Each crown of *E. tereticornis* hosting *A. miquelii* was divided into four equal quadrants using a compass, with each quadrant centred on a different aspect (north, south, east or west). Within each quadrant the number of *A. miquelii* were counted. Quadrants proximate to the river and built environment were recorded. By dividing the crown in four quadrants

that radiated around the trunk of the host tree, these quadrants incorporated both height and width of the crown to assess radial aggregation of mistletoe.

DATA ANALYSIS

To answer research question 1 and assess the overall spatial distribution pattern of *A. miquelii*, quadrant density (the number of individual mistletoe plants per quadrant (x)), the sample variance (S^2) and mean ($\bar{x}$) were calculated to determine the coefficient of dispersion ($S^2/\bar{x}$). Using a contingency table of expected and observed sample frequencies, the fit of the data was compared to the Poisson distribution to determine the population dispersion pattern of *A. miquelii* within host tree crowns. A χ^2 test was used to test whether any deviation from the Poisson distribution was statistically significant.

To answer research question 2 and identify size differences in *E. tereticornis* where *A. miquelii* was present and absent, the mean DBH, tree height and crown diameter were calculated and independent t-tests used to determine if any differences were significant. Scatterplots were used to identify relationships between tree size (DBH, tree height and crown diameter) and mistletoe density in all surveyed *E. tereticornis* hosting *A. miquelii* and regression analysis applied to identify significant correlations.

To answer research question 3, for all surveyed *E. tereticornis* hosting *A. miquelii*, trends between the number of individual mistletoes in "Built" quadrants and "River" were explored using bar graphs. A Wilcoxon sign ranked test was used to determine the significance of any difference. To answer research question 4 and determine if mistletoe exhibited any bias in radial distribution around the crown, differences in mistletoe density per quadrant (north, south, east, west) were visually inspected using bar graphs, and statistical differences analysed using generalised linear models assuming a Poisson error distribution and a natural logarithm link (Poisson GLM) for specific size categories of host tree. This analysis used only two size classes of *E. tereticornis* based on crown diameter (34 trees with a 12 m crown diameter and 30 trees 16 m crown diameter) This ensured all quadrants were of the same size for each Poisson GLM procedure. To avoid bias in the results, other host tree size classes were excluded from this analysis as there was an uneven representation of the river across all aspects. To explore potential measurement error, *A. miquelii* were resampled within these two size classes of *E. tereticornis* and the coefficient of variation compared to identify the extent of variation between sampling efforts. All data analysis was completed in R version 3.2.3 (R Development Team, 2015) with the threshold for statistical significance taken as $p < 0.05$.

RESULTS

In total, 184 *E. tereticornis*, including 133 trees with *A. miquelii* and 51 without *A. miquelii*, were surveyed. Where *A. miquelii* was present, 969 individual plants were recorded across 532 quadrants. The number of mistletoe per tree ranged from 1 to 43 and the number of mistletoe per quadrant ranged from 0 to 28. The mean mistletoe density per tree (± SE) was 7.28 ± 0.61 and mean mistletoe density per quadrant (± SE) was 1.82 ± 0.13. Mean mistletoe density per aspect (± SE) was greatest in the north (3.19 ± 0.36) and lowest in the south (0.87 ± 0.13) (Table 1).

The sampled population of *A. miquelii* was found to be aggregated within host tree crowns. The calculated coefficient of dispersion ($S2/\bar{x}$) for the 969 A. miquelii within 532 quadrants in 133 E. tereticornis was 5.00 which suggested an aggregated spatial distribution pattern when compared to a random pattern under the Poisson distribution. Results of the $\chi 2$ test confirmed the observed pattern of aggregation significantly deviated from the expected random pattern ($\chi 2$ = 178.99, df = 8, $p < 0.001$).

TABLE 1. Number of *A. miquelii* per quadrant (aspect) across the 532 quadrats within the 133 host *E. tereticornis*.

	Number of *A. miquelii*		
Quadrant	**N**	**Mean**	**SE**
North	424	3.19	0.36
East	191	1.43	0.17
South	116	0.87	0.13
West	238	2.01	0.29

Independent t-tests showed that *E. tereticornis* hosting mistletoe were significantly taller ($t = -2.4991$, $df = 182$, $p = 0.0133$), with larger crowns ($t = -3.493$, $df = 182$, $p = 0.0005$) than *E. tereticornis* without mistletoe (Table 2). There was no significant difference in the mean diameter at breast height ($t = 0.785$, $df = 182$, $p = 0.4336$). Scatterplots showed *A.miquelii* density increased with host tree size (Figure 1). The results of correlation analysis revealed significant positive linear relationships between mistletoe density and DBH ($r = 0.1812$, $n = 133$, $p = 0.0368$), tree height ($r = 0.2073$, $n = 133$, $p = 0.0166$) and crown diameter ($r = 0.2457$, $n = 133$, $p = 0.0043$).

In the 133 *E. tereticornis* hosting the 969 individual *A. miquelii*, the mean mistletoe density (± SE) in the half of the crown proximate to the Brisbane River was 5.83 ± 0.48 compared to 1.45 ± SE in the opposite half, closest to the built environment (Figure 2). The results of a Wilcoxon sign rank test confirmed mistletoe density was significantly greater on the riverside ($V = 7864$, $p < 0.0001$).

When the influence of aspect was examined, a trend that suggested *A. miquelii* occurred in higher density in the northern quadrant was identified in the two size classes of *E. tereticornis* selected to test if *A. miquelii* exhibited a directional bias (Figure 3). Importantly, in these two size classes the influence of the river was not confounding as it was represented across all aspects (Table 3).

The results of the Poisson GLM procedures revealed that in the 34 *E. tereticornis* with a 12 m crown diameter, *A. miquelii* occurred at a significantly higher rate in the northern quadrant compared to the eastern ($p = 0.0421$), southern ($p = 0.0014$) and western ($p = 0.0477$) quadrants. Further, mistletoe density was not significantly different between the eastern, southern, and western quadrants (Table 4). The results of the Poisson GLM on the 30 trees with a 16 m crown diameter revealed similar results: mistletoe was again found to occur significantly more in the northern quadrant compared to the eastern ($p = 0.0286$), southern ($p = 0.0043$) and western ($p = 0.0262$) quadrants. Again, there was no significant difference in mistletoe density between the southern, western and eastern quadrants (Table 4).

DISCUSSION

The pattern of dispersion shown by a population often indicates the operation of specific abiotic and/or biotic factors affecting the ongoing survival of individuals. We found *A. miquelii* was more abundant on the side of the host tree facing away from the built environment, and facing towards the Brisbane River. We also found that mistletoe occurred in greater densities in northern quadrants compared to all other aspects. These findings are possibly a consequence of

TABLE 2. Summary table of results from t-tests comparing size of *E. tereticornis* where *A. miquelii* is present or absent.

	***A. miquelii* present**			***A. miquelii* absent**			**t-test comparison**	
	Mean	**SE**	**n**	**Mean**	**SE**	**n**	**t**	**p value**
DBH (cm)	70.16	2.69	133	65.86	5.42	51	0.785	0.4336
Tree height (m)	16.02	0.70	133	17.98	0.40	51	2.499	0.0133
Crown diameter (m)	9.33	0.54	133	11.53	0.33	51	3.493	0.0005

TABLE 3. Orientation of trees with respect to river in two crown size classes (12 m, 16 m diameter).

Crown size class	**Aspect**	**North**	**South**	**Total**
12m	East	9	8	17
	West	10	7	17
	Total	19	15	
16m	East	7	9	16
	West	8	6	14
	Total	15	15	

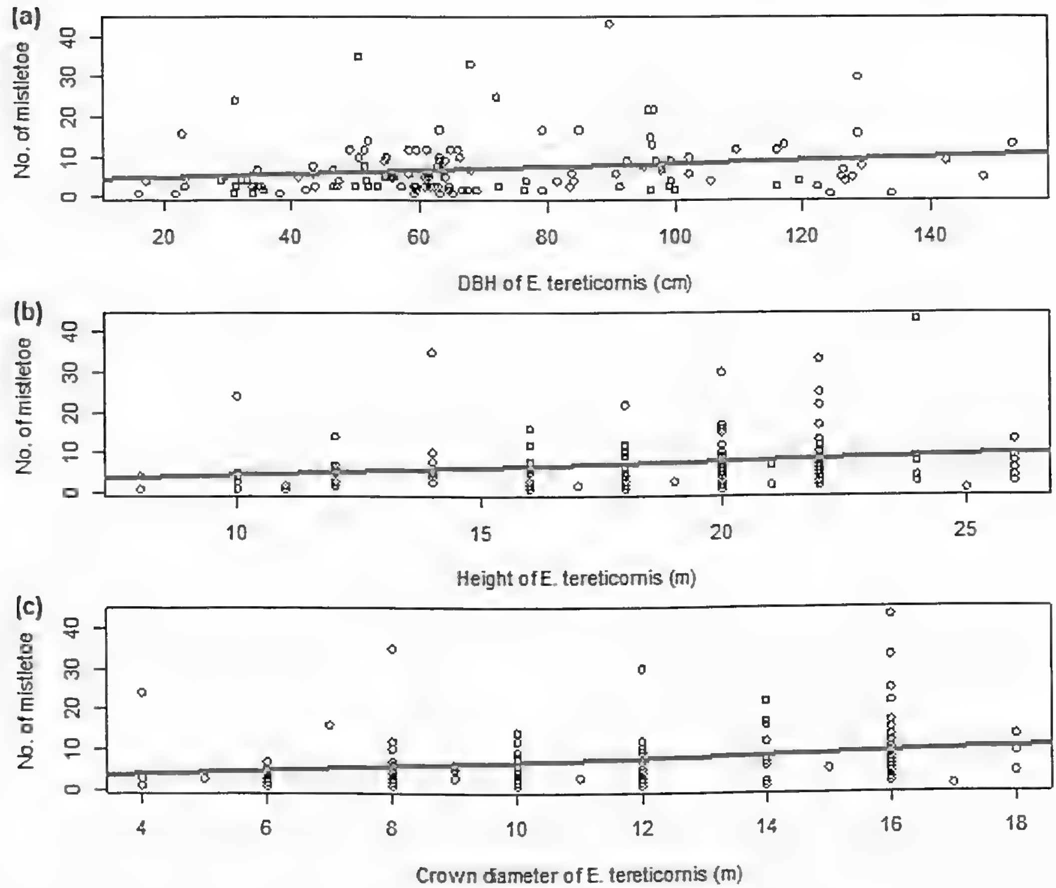

FIG. 1. Scatterplots showing significant positive linear relationship between mistletoe density and size metrics of *E. tereticornis* hosting *A. miquelii*: (a) DBH (cm) ($r = 0.1812$, $n = 133$, $p = 0.0368$), (b) tree height (m) ($r = 0.2073$, $n = 133$, $p = 0.0166$) and (c) crown diameter (m) ($r = 0.2457$, $n = 133$, $p = 0.0043$).

TABLE 4. Matrix of p-values generated from testing differences in *A. miquelii* density in quadrats with a Poisson GLM in *E. tereticornis*. Upper panel shows values for the 12 m crown diameter size class (quadrat volume ~206 m³). Lower panel shows values for the 16 m crown diameter size class (quadrat volume ~536 m³). Significant p-values ($p<0.05$) highlighted in bold.

Crown size class	Aspect	North	East	South	West
12 m	North	-	**0.0421**	**0.0014**	**0.0477**
	East		-	0.1418	0.9527
	South			-	0.3745
	West				-
16m	North	-	**0.0286**	**0.0043**	**0.0262**
	East		-	0.4043	0.9672
	South			-	0.4277
	West				-

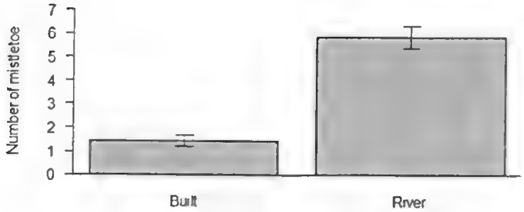

FIG. 2. Bar plot of mean *A. miquelii* density in the two quadrants proximate to the Brisbane River and the two quadrants closest to the built environment ± standard errors. Mean mistletoe density was found to be significantly greater in the two quadrants that faced the Brisbane River (5.83 ± 0.48) compared to the two quadrants that faced the built environment (1.45 ± 0.23) ($V = 7864$, $p < 0.0001$).

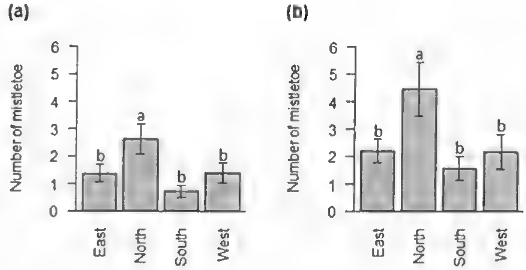

FIG. 3. Bar plot of mean mistletoe density per quadrant ± standard errors in (a) 34 *E. tereticornis* with a 12 m crown diameter and (b) 30 *E. tereticornis* with a 16 m crown diameter. For (a) mean mistletoe density was significantly greater in the northern quadrants (2.62 ± 0.55) compared to eastern (1.38 ± 0.32, $p = 0.0421$), southern (0.74 ± 0.22, $p = 0.0014$) and western (1.41± 0.36, $p = 0.0477$) quadrants. For (b) mean mistletoe density was significantly greater in the northern quadrants (4.47 ± 0.99) compared to eastern (2.20 ± 0.43, $p = 0.0286$), southern (1.57 ± 0.42, $p = 0.0043$) and western (2.16 ± SE= 0.63, $p = 0.0262$) quadrants.

foraging behaviour of the mistletoebird, and to a lesser extent, variation in abiotic conditions, principally light availability, within the host tree crown.

AGGREGATION AND DENSITY: MISTLETOEBIRD AND HOST TREE

Although many species of frugivore birds disperse mistletoe seed, close mutualistic relationships exist between specific species and mistletoe (Reid, 1991). For *A. miquelii*, it is widely accepted that the Australian mistletoebird (*Dicaeum hirundinaceum*) is the most efficient disperser and therefore strongly influences its spatial distribution pattern (Reid, 1991; Watson, 2002; Ward, 2005). Mistletoebirds are attracted to fruiting plants and prolonged feeding, together with the short gut passage time of the seed, results in deposition of seed close to the parent plant (Richardson & Wooler, 1988; Murphy et al., 1993; Ward & Patton, 2007; Rawsthorne et al., 2012).

Several studies have shown mistletoe density to be positively correlated to host tree size (Overton, 1994, Martinez del Rio et al., 1995, Lei 1999; Aukema & Martinez del Rio, 2002; Shaw et al., 2005; Matula et al., 2015; Pérez-Crespo et al., 2016). Consistent with those studies, we found mistletoe is likely to occur in greater densities on larger host trees. In the context of the urban environment, larger canopies are likely to provide additional shelter for bird dispersers to feed, digest and deposit mistletoe seed (Aukema & Martinez del Rio, 2002). Taller trees with large canopies are also likely to be the oldest and therefore have a greater chance of accumulating infections over time (Lei, 1999).

ABIOTIC FACTORS: WATER AND LIGHT AVAILABILITY

Water and light availability, together with temperature, have long been recognised as abiotic factors influencing plant distributions (Taylor & Burns, 2016). As *A. miquelii* is a hemi-parasitic plant that relies on the host tree for water, and requires sufficient light to produce photosynthetic products, its position is likely to be restricted to areas of the crown that optimise access to these resources (Shaw & Weiss, 2000; Taylor & Burns, 2016). Water and light availability are particularly important for the successful establishment of mistletoe within host trees as mistletoe seeds are photosynthetically active, lack a seed coat and are prone to desiccation. Areas of the host tree canopy which receive increased light and humidity may therefore promote germination and successful establishment of seedlings.

Several studies have shown that mistletoe species consistently occur in higher areas of the host tree crown and in higher density along forest edges and roadsides due to increased light and/or water availability (Norton & Smith, 1999; Shaw & Weiss, 2000). However, in the context of this study, we

suggest water availability is unlikely to be different within the crown of *E. tereticornis*, particularly as all host trees surveyed were located in close proximity to the Brisbane River. Further, hemiparasitic mistletoe have been shown to be more reliant on the provision of water by the host tree than microclimate humidity to meet their water requirements and therefore are unlikely to benefit from any potential difference in humidity on the river side of the host tree (Ehleringer et al., 1986; Taylor & Burns, 2016). We therefore argue that light availability is a more plausible abiotic factor associated with the non-random mistletoe distribution we observe.

The focus of most studies in this area has been on the vertical and horizontal distribution of mistletoe within host trees. Research has shown that infections radiate outwards and upwards from the centre of the host tree in part due to the increased availability of light in the upper canopy (Shaw & Weiss, 2000). As far as we are aware, this study is only the second to examine the radial distribution of mistletoe based on aspect (Taylor & Burns, 2016). Aspect was first examined in a study of mistletoe (family Loranthaceae) parasitising southern beech trees (family Nothofagaceae) in New Zealand, where it was found mistletoe aggregated on the northwestern side of the host tree due to greater light availability (Taylor & Burns, 2016). Our results were similar, as mistletoe was found to be in highest densities in the northern aspect, which, at the latitude of the study area, receives the most sunlight and likely provides the most favourable position for *A. miquelii* to produce photoassimilates.

BIOTIC FACTORS: BEHAVIOUR OF MISTLETOEBIRD

Whilst recognising the importance of light availability, the directional bias towards the northern quadrant observed in this study could also be a consequence of foraging behaviour and perching preferences of the mistletoebird. In the study area, *A. miquelii* is known to fruit predominately in the cooler winter and spring months than at any other time of the year (Watson, 2011). As the mistletoebird displays a preference for foraging in the morning, it is possible that the northern quadrant of *E. tereticornis* is favoured by foraging birds; the aspect receiving the most sunlight and therefore warmest area of the crown. Perching preferences of the mistletoebird may also explain the directional bias towards the river and away from the built environment found in our study. In the context of urban parkland, mistletoebirds may seek the protection afforded on the river side of the crown. This may be to avoid aggressive species such as noisy miners (*Manorina melanocephala*) or other disturbance generated from urban activity (Montague-Drake et al., 2011; Barati et al., 2016). These suggestions are speculative and further research would be needed to test the hypotheses arising from this work.

Other factors which could explain the observed pattern of distribution include the behaviour of common herbivores in the urban environment known to feed on *A. miquelii*, such as brush-tailed possums (*Trichosurus vulpecula*) and various species of butterfly larvae (Watson 2001). These herbivores may exhibit some bias in activity against the northern area or river side of the host tree crown due to increased risk of predation. Again, this is speculative and additional research is needed to investigate this further.

CONCLUSION

This study serves as a preliminary investigation into understanding the factors that influence the spatial distribution of *A. miquelii* in an urban environment. Our results show that *A. miquelii* distribution is biased towards certain areas of the host tree crown; provides information relevant to management of *A. miquelii*; and raises questions regarding the potential impact of urbanisation on foraging behaviour of the Australian mistletoebird. Patterns we observe may be related to foraging behaviour and perching preferences of the Australian mistletoebird. Further research is needed to examine the foraging behavior of the Australian mistletoebird in an urban setting while *A. miquelii* is in fruit to test the hypotheses posed in this paper.

ACKNOWLEDGEMENTS

This project was conducted by MDH as part of a third-year undergraduate course "3331ENV *Ecology and Conservation of Populations*" supervised by DJS at the School of Environment, Griffith University, Nathan Campus. The authors thank Irene Reddecliffe for assistance with data collection, Dr James McBroom for statistical advice, and all students of 3331ENV in 2017 for helpful feedback. The authors also acknowledge contributions made by anonymous referees who provided feedback on the original manuscript.

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APPENDIX A. Parkland along Brisbane River used as study sites.

Suburb	Parkland	GPS coordinates
Fairfield	Brisbane Corso	27°30'18.3"S 153°01'06.4"E
Yeronga	South Brisbane Corso	27°30'20.6"S 153°00'37.1"E
	Paringa Place	27°30'44.5"S 153°00'01.4"E
	Esplanade Park	27°30'51.5"S 153°00'01.6"E
Sherwood	Sherwood Arboretum	27°31'52.8"S 152°58'21.4"E
Graceville	Simpsons Playground	27°31'27.5"S 152°59'36.2"E
Yeerongapilly	Ken Fletcher Park	27°31'26.6"S 153°00'21.7"E
Jindalee	Amazon Place Park	27°31'47.0"S 152°57'03.3"E
Sinnamon Park	John Magee Park	27°32'02.7"S 152°57'23.9"E
Seventeen Mile Rocks	Rocks Riverside Park	27°32'27.6"S 152°57'41.0"E
St Lucia	University of Queensland	27°29'55.7"S 153°01'11.4"E
	Esplanade Park	27°30'17.2"S 153°00'13.5"E
Fig Tree Pocket	Mandalay Park	27°32'28.6"S 152°58'24.7"E
	Un-named park west of Kenmore Park (access via Centenary Bikeway)	27°31'36.4"S 152°56'53.9"E

A REVISION OF *TERELLUM DELICATUM* KURODA AND KAWAMOTO IN KAWAMOTO AND TANABE, 1956 (GASTROPODA, SERAPHSIDAE)

MAXWELL, S. J.[1], LIVERANI, V.[2], RYMER, T. L.[3] & CONGDON, B. C.[4]

There has been confusion on the status of *Terebellum delicatum* Kuroda & Kawamoto in Kawamoto & Tanabe 1956, which has often erroneously been referred to as a colour form of *Terebellum terebellum* Linné 1758. The taxon *T. delicatum* is revised, giving precision regarding authorship, and a translation of the original Japanese description with a further refinement of the described features that assist in species recognition. Notes on the designation of a lectotype are presented.

Key words: Taxonomy, Species, Indo-Pacific, Mollusca, Seraphsidae, Terebellum.

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INTRODUCTION

The last ten years has seen a resurgence in the study of seraphsid gastropods (Caze *et al.* 2010; Liverani 2013; Poppe & Tagaro 2016). This rejuvenated interest has led to the reassessment of the number of living in Seraphsidae (Liverani 2013; Poppe & Tagaro 2016). One of these taxa, *Terebellum delicatum* Kuroda & Kawamoto in Kawamoto & Tanabe 1956, was historically recognized as a valid species only by contemporary Japanese malacologists (Kira 1959; Habe 1961). Outside of Japan however, it was relegated by other taxonomists to a synonymic colour variation under *Terebellum terebellum* Linné 1758 by Jung & Abbott (1967). Recent workers have noted conchological differences, aside from the original description, that sets this species apart from other members of the *Terebellum* Röding 1798 (Liverani 2013; Poppe & Tagaro 2016). These differences indicate that *T. delicatum* is a distinctive phenetic species, and not a subspecies of *T. terebellum* as determined by Kuroda & Kawamoto (1956).

It is well known that the species *T. terebellum* is variable in size, solidity of the shell, height of spire and particularly in shell colour and pattern. Several synonyms based on shell colour variation and patterning have been published such as: *T. nebulosum* Röding 1798, *T. lineatum* Röding 1798, *T. punctulorum* Röding 1798. When a large series of specimens is examined, all these defined patterns have some intermediates among them (Figures 1 and 2). However, all these colour forms possess consistent morphological characters and life history characteristics that permit attribution to a single species, *T. terebellum* (Abbott 1962; Jung & Abbott 1967; Jung 1974). In contrast to the more variable *T. terebellum*, *T. delicatum* maintains a constant shell pattern throughout its geographical distribution.

This review of the taxon *T. delicatum* has three main foci: first, to provide a systematic context through a literary examination of the family and genus, enabling the formation of a synonymic list and description of these taxonomic ranks; second, to provide insights into the history of authorship claims and dates of publication of *T. delicatum*; and third, to revise the description based on type and other examples from across the species range in order to provide a refined description that highlights key species-specific shell morphology, thus showing that *T. delicatum* is readily

distinguishable from its sister taxa. The current family and generic placement of *T. delicatum* is based on Jung (1974). This review also examined the taxonomy of the family Seraphsidae Jung 1974 and the genus *Terebellum* Röding 1798.

METHODS AND MATERIALS

This review examined the taxonomy of *T. delicatum*, and sought to explain or correct the discrepancy between the use of Kuroda & Kawamoto 1961 for the authorship when the literature indicates precedence should go to Kuroda & Kawamoto in Kawamoto & Tanabe 1956 (see Liverani 2013; Poppe & Tagaro 2016).

It is only recently that there has been an elevation of *T. delicatum* from either a form or subspecies of *T. terebellum* (Kuroda & Kawamoto in Kawamoto & Tanabe 1956; Jung & Abbott 1967; Jung 1974; Liverani 2013; Poppe & Tagaro 2016). This current review examined the definition and description of *T. delicatum* relative to type material to improve current understanding of the species.

In determining the higher taxonomy of *T. delicatum*, this review also examined the Bouchet and Rocroi (2005) arguments for precedence of the elevated Seraphina Gray (1853) to the rank of family over Seraphsidae Jung (1974). In particular, the relegation to the synonymy of Seraphsidae Grey (1853) ex Bouchet *et al.* (2017) of Seraphsidae Jung (1974) as a consequence of a spelling shift of Seraphidae Gray (1853) ex (Bouchet and Rocroi (2005), by testing these arguments against the International Commission on Zoological Nomenclature (ICZN 1999) articles on precedence, availability of any other known alternatives, as well as designated type material. From this information, an annotated family level synonymy was generated, the precedence of names determined, and a revised description formulated.

MATERIAL EXAMINED

Two forms of material were used in this review. The first was the type material for *T. delicatum* currently held in the Hagi City Museum, Japan (specimen no. HH-Mo 000214). The second was physical and photographic observations made from the five privately owned systematic collections of Valda Cantamessa, Conchology Inc, Virgilio Liverani, Stephen Maxwell and Uwe Weinreich. Material and published images from these collections were chosen due to reliability in location data. This reliability stems from each collection being primarily based on self-collected material with known collection locations, and/or providing an extensive range of comparative specimens. Literary references for specimen localities are problematic as the locality references generally lack supportive illustrated material. In addition, there is a high possibility of taxonomic confusion between species in the literature given the long historical relegation of *T. delicatum* as a form or synonym of *T. terebellum* (Jung & Abbott 1967; Jung 1974). Consequently, this current review focused on physical material held in the observed systematic collections.

SYSTEMATICS

Caenogastropoda Cuvier, 1797
Sorbeoconcha Ponder & Linberg, 1987
Stromboidea Rafinesque, 1815

SERAPHSIDAE
JUNG, 1974

SYNONYMY

1853 Seraphina Gray, 11(62), p. 131. Type: *Seraphys* Gray, 1847 (= *Seraphs* Montfort 1810). Subfamily of Strombidae.

= 1871 Seraphyinae Gill, 1870 ex Gill, 227, p. 9. Type: *Terebellum terebellum* Linné, 1758. Synonymized - Emendation of original name Seraphina Gray 1853.

= 2005 Seraphidae Gray, 1853 ex Bouchet & Rocroi, 47(1-2), p. 253. Bandel, 2007, C 524, p. 136. Type: *Seraphs* Montfort, 1810. Synonymized - Emendation of original name Seraphina Gray, 1853. Excluded - ICZN (1999) article 35.5 which rules that the elevation of a subfamily shall not displace the name given to a family, even if that subfamily has precedence: "Precedence for names in use at higher rank- If after 1999 a name in use for a family-group taxon (e.g. for a subfamily) is found to be older than a name in prevailing usage for a taxon at higher rank in the same family-group taxon (e.g. for the family within which the older name is the name of a subfamily) the older name is not to displace the younger name" (ICZN 1999, Article 35.5). Furthermore, Article 50.3.1 is not applicable to argument for relegation of Seraphsidae Jung as it makes two base assumptions: first, that Gray (1853) made a spelling error, which cannot be substantiated; and second, the question of priority here does not deal with an intrasubspecific taxon, being the retrospecive elevation of a prior subfamily

name to replace a later family name after 1999 (Article 35.5), and is therefore an argumnet of priority at rank.

= 2010 Seraphsidae Gray, 1853 ex Bouchet *et al.*, 2017. Type: *Terebellum* Bruguière, 1798 (= *Terebellum* Roding, 1798). Synonymized – Emendation of original name Seraphidae Gray, 1853 ex Bouchet and Rocroi, 2005.

= 1858 Terebellinae Adams & Adams, p. 262. de Gregorio, 1880, *Fauna di S. Giovanni Ilarione*, p. 19. Type: *Terebellum terebellum* Linné, 1758. Excluded - Preoccupation = *Terebellinae* (Polychaeta, Terebellidae).

= 1893 Terebellidae Sacco, p. 21. Type: *Terebellum terebellum* Linné 1758. Excluded - Preoccupation = *Terebellinae* (Polychaeta, Terebellidae).

= 1974 Seraphsidae Jung, 7, p. 12. Caze *et al.*, 2010, 32(3) p. 426. Type: *Seraphs* Montfort, 1810.

DESCRIPTION

Shell is typically long and narrow, with the last whorl extending over much of the earlier whorls. The stromboidal notch is not well developed or is absent.

TEREBELLUM RÖDING 1798

SYNONYMY

= 1753 *Terebellum* Klein, p. 38. Sowerby, 1820-1825, pl. 263. Mörch, 1852, p. 63. Adams & Adams, 1858, p. 263. Excluded - pre-Linné (1758).

= 1798 *Terebellum* Röding, p. 135. p. Horst & Schepman, 1908, p. 223. Type: *Terebellum nebulosum* Röding 1798 (= *Bulla terebellum* Gmelin, 1791 = *Terebellum terebellum* Linné, 1758). Eames, 1952, *236*(631), p. 72. Bandel, 2007, C 524, p. 137.

= *Terebellum* Lamarck, 1799, p. 69. Lamarck, 1801, p. 72. Type: *Bulla terebellum* Linné, 1758 (= *Terebellum terebellum* Linné, 1758). Synonymized.

= *Terebellum* Montfort, 1810, p. 379. Type: *Terebellum subulatum* Lamarck, 1810 (= *Terebellum terebellum* Linné, 1758). Synonymized.

= *Terebrina* Rafinesque, 1815, p. 145. Synonymized - Emendation of *Terebellum* Lamarck, 1799.

= 1848 *Lucis* Gistel, p. 171. p. 72. Type: *Lucis subulatum* Lamarck, 1810 (= *Terebellum terebellum* Linné, 1758). Synonymized.

= 1848 *Artopoia* Gistel, pl 7, fig. 8. p. 72. Type: *Artopoia* (*Terebellum*) *subulata* Lamarck, 1810 (= *Terebellum terebellum* Linné, 1758). Synonymized.

= *Artopoja* Gistel ex Paetel, 1888, p. 315.

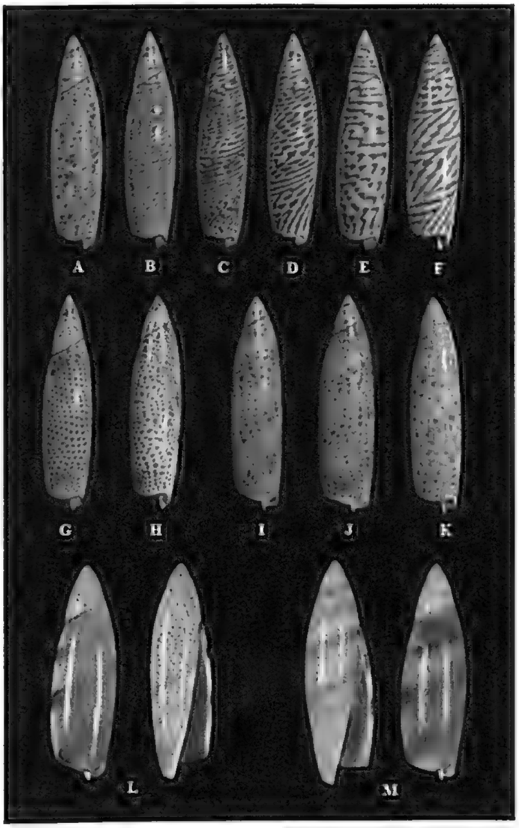

FIG. 1. The three extant members of the *Terebellum* Röding. 1) *T. terebellum* Linné: (A) the typical pattern, 55 mm, Nha Trang, Vietnam; (B) short lines pattern, 59.5 mm, Noumea, New Caledonia; (C) dots and lines pattern, 55.5 mm, Chennai, India; (D) dots and lines pattern, 56.5 mm, Chennai, India; (E) discontinuous undulating lines, 59 mm, Noumea, New Caledonia; (F) "lineatum" pattern, 41 mm, Nha Trang, Vietnam; (G) "punctulorum" pattern, 50.5 mm, Noumea, New Caledonia; (H) "punctulorum" pattern, 50 mm, Nha Trang, Vietnam. 2) *T. delicatum* Kuroda and Kawamoto in Kawamoto and Tanabe: (I) 35.5 mm, Nacala bay, Mozambique; (J) 37 mm, Nacala Bay, Mozambique?; (K) 29.5 mm, Bowen Sand Flats, QLD, Australia. 3) *T. hubrechti* Poppe and Tagaro, (L) holotype, 33.2 mm, Caubian deep, Bohol, Philippines. 4) Cf. *T. hubrechti* (M) 44.6 mm Bohol Island, Philippines.

DESCRIPTION

The shell is convolute, with an evolute growth pattern. The shell lacks a posterior canal and is widest anteriorly. Typically, the shell is smooth, or with greatly reduced sculpture where present. The labrum of the shell is protocyst, and there is a channeled suture between the whorls. The aperture is long and narrowing anteriorly with a smooth columella. The labium is calloused and extends just above the apex. The basal sinus is present but shallow. At present there are three species within the genus *Terebellum*: *T. hubrechti* Poppe & Tagaro, 2016, *T. terebellum* Linné,1758, and the subject of this revision *T. delicatum* Kuroda & Kawamoto in Kawamoto & Tanabe, 1956 (Figure 1).

TEREBELLUM DELICATUM
KURODA & KAWAMOTO IN KAWAMOTO & TANABE, 1956

SYNONYMY

= *Terebellum terebellum delicatum* Kuroda & Kawamoto in Kawamoto & Tanabe, 1956, p. 87, pl. 10, fig. 91. *Terebellum delicatum* was first introduced in the monographic work "Catalogue of Molluscan Shells of Yamaguti Prefecture" (Kawamoto & Tanabe 1956). The part "Descriptions of New Species" was written by T. Kuroda & T. Kawamoto (H. Fukuda pers. comm.).

= *Terebellum t. delicatum* Kuroda & Kawamoto - Kira, 1959, p. 34. (cited in the description of *T. terebellum*, not figured).

= *Terebellum terebellum delicatum* Kuroda & Kawamoto - Habe, 1961: p. 58, pl. 17, fig 1.

= *Terebellum t. delicatum* Kuroda & Kawamoto - Kira, 1962, p. 34. (cited in the description of *T. terebellum*, not figured).

= *Terebellum terebellum delicatum* Kuroda & Kawamoto - Habe, 1964: p. 58, plate 17, fig 1. Kreipl & Poppe, 1999, p. 10, pl. 8 fig. 5.

= *Terebellum terebellum* forma *delicatum* Kuroda & Kawamoto, 1961- Jung & Abbott, 1967, p. 449, pl. 321, figs. 9, 10.

= *Terebellum delicatum* Kuroda & Kawamoto, 1961 - Liverani, 2013, p. 15, pl. 132 figs 1-4.

= *Terebellum delicatum* Kuroda & Kawamoto, 1961 - Poppe & Tagaro, 2016, p. 93, pl. 8 fig. 6.

DESCRIPTION

"*This is the inland sea form of T. terebellum (Linne). Compared with the nominate form it is smaller and thinner; with a coloration that is usually a white background covered with fine brown spots, and the spire is short. Length 34 mm, width 9 mm. T. terebellum which is widely distributed in the Indo-Pacific has a white background with various patterns of vague cloudy spots and spiral bands and a larger shell (60 mm x 15 mm) and the spire is taller and more protruding, by all of which it can be distinguished from T. terebellum delicatum. This latter is probably distinguished ecologically; in Okinawa, the Philippines and elsewhere both forms exist but only the thin-shelled one is found in inland seas so it cannot be considered a mere variant. We are giving it a new name in anticipation of future studies*" (Kawamoto & Tanabe 1956, p. 87 translated by Paul Callomon).

This original description gives the colour as "*usually a white background covered with fine brown spots*" (Kawamoto & Tanabe 1956, p. 87). This description is vague, and could include colour forms of *T. terebellum*. Therefore, it is necessary for clarity in taxonomic differentiation to amend this description based on the type to include: background colour is usually tan with circular white spotting, with a single dark smaller spot within each larger white one such that there circumferences touch, resulting in a white crescent shape partially surrounding the darker spot.

Also absent from the original description is the thickened, white, 9-7 mm long axial ridge about the middle of the columella found on the typical shell of *T. delicatum*. In contrast, *T. terebellum* typically has a thickening of the columella callus near the posterior canal, which continues into the thin callus of the spiral sutural slit. However, adult shells with no thickened callus are common in both species. In these cases the discerning characters are consistent differences in the coiling of the spire and the colour pattern. The spire of *T. delicatum* is less coiled than the spire of *T. terebellum*, with 2.5 whorls. In contrast, the spire of *T. terebellum* consists typically of 3-3.5 whorls. The aperture of *T. delicatum* is comparatively longer than in *T. terebellum*. The shape of the last whorl is cylindrical in both species, but more straight-sided in *T. delicatum*.

TYPE MATERIAL

The authors hereby select specimen no. HH-Mo 000214, preserved in Hagi City Museum, as the lectotype of *Terebellum delicatum* Kuroda and Kawamoto in Kawamoto and Tanabe, 1956 (Figure 2A). This is the only surviving specimen from a

lot originally registered as eight syntypes. It was collected from Kurae, Hagi, Japan by Y. Ikeda in 1955. It measures 29.0 mm in length with a width of 6.5 mm. This remaining type is a juvenile example of the species, with a broken lip, and colour that has faded, but from shape and pattern it can be discerned as a specimen of *T. delicatum* (*sensu* Habe, 1961; Liverani, 2013; Poppe & Tagaro, 2016).

MATERIAL EXAMINED

Japan: Kurae, Hagi, Japan, lectotype no. HH-Mo 000214, 29 mm., Hagi City Museum; Vietnam: Nha Trang area, x 26, 24.0-37.0 mm (Virgilio Liverani coll. n. 1901-01); Australia: Bowen Sand Flats x 1, 29.5 mm (Stephen Maxwell coll.); Buchans Point x 3, 19.0-27.0 mm (Uwe Weinreich coll.); Dingo Beach, Queensland x 5 (x 4 Valda Cantamessa coll.; x 1 Stephen Maxwell coll.); Saunders Beach x 1 Juv. (Stephen Maxwell coll.); Torres Straits x 1 (Uwe Weinreich coll.); Wonga Beach x 1 (Uwe Weinreich coll.); Mozambique: Nacala Bay x 6, 32.0-37.0 mm (Virgilio Liverani coll. n. 1901-02). In addition to these physical samples, images of several specimens from the Philippines: Albuera, Leyte, were also examined (Conchology Inc. coll.).

DISTRIBUTION

Specimens of *T. delicatum* examined in this study have been found in south-west Japan, Vietnam, Philippines, and recently in Queensland, Australia. While first hand collecting records from indicate that the species has been found periodically intertidally in Queensland (SM pers. coll.), this is in contrast to reports of a more restricted range to deeper waters in the Philippines (Poppe & Tagaro 2016). Records from Mozambique need to be confirmed, as they are located well outside the Western Pacific rim where the species is known to occur. Furthermore, these specimens were obtained via a commercial dealer, who in turn relied on data passed along with the specimens that cannot be validated, as first hand source information is lost (Liverani, pers. coll.).

DISCUSSION

This revision expands the description of *T. delicatum* to give a higher level of taxonomic clarity. The illustration accompanying the original description (Kawamoto & Tanabe 1956, pl. 10, fig. 91) is of poor quality, and does not allow for clear identification of the key features. Although Liverani (2013) accepted *T. delicatum* as a valid species, the indistinct nature of this illustration of a syntype of *T. delicatum* could pose difficulty for the identity of the species from the literary record. A major factor contributing to confusion regarding the correct taxonomic understanding of *T. delicatum* is differences between the original image of *T. delicatum* and those published by subsequent authors. The description of the colour pattern in the original description is misleading, similar to that of the "punctulorum" form of *T. terebellum*. Habe (1961, p. 38, pl. 17) was the first to publish a clear image of *T. delicatum* (as *T. t.* ssp. *delicatum*) that agrees with the surviving lectotype. However, we are unable to conclude whether the original type series consisted of only *T. delicatum* as we now understand it, or whether

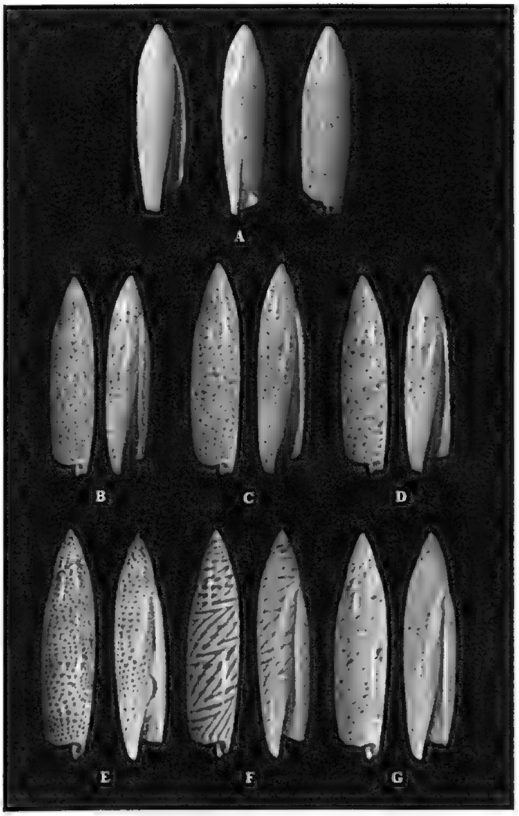

FIG. 2. Contrasting *T. terebellum* Linné and *T. delicatum* Kuroda and Kawamoto in Kawamoto and Tanabe: *T. delicatum*: (A) lectotype hereby selected, 29 mm, Kurae, Hagi, Japan; (B) 35 mm, Nha Trang, Vietnam; (C) 37 mm, Nha Trang, Vietnam; (D) 30 mm, Nha Trang, Vietnam. 2) *T. terebellum* Linné; (E) "punctulorum " pattern, 50 mm, Nha Trang, Vietnam; (F) "lineatum" pattern, 41 mm, Nha Trang, Vietnam; (G) the more common pattern, 37 mm, Nha Trang, Vietnam.

it was a mixture of both *T. terebellum* and *T. delicatum* purely based on description of the colouration due to the loss of the majority of the type material.

CONCLUSION

This review determined that much of the confusion between the two valid species, *T. delicatum* and *T. terebellum*, arises from a lack of a clear illustration of the designated type material, as well as a failure to sight the taxonomy prior to 1961. The incorrect date of 1961 for the publication of *T. delicatum* in Jung & Abbott (1974), Liverani (2013), and Poppe & Tagaro (2016) derives from Jung & Abbott's assumption that Habe (1961) was the first publication of *T. delicatum*. *Terebellum delicatum* should not be seen as a subspecies, as they are sympatric, or colour form of *T. terebellum*. The recognised colour forms of *T. terebellum* intergrade, in contrast, there are no intergrades in pattern between *T. delicatum* and *T. terebellum*.

ACKNOWLEDGEMENTS

We are grateful for the assistance offered by Hiroshi Fukuda, Okayama University, Japan, for comments offered on the Japanese text, and the friendly help given finding the repository of the type material of *T. delicatum*. We especially thank S. Hori, Hagi City Museum, Japan, for the effort spent in search of these little shells in the collections of the Museum, resulted in the finding of the surviving lectotype and relative photos. We thank Guido Poppe and Sheila Tagaro for allowing use of the images of the type material of *T. hubrechti*. The authors thank Gijs C. Kronenberg and Aart H. Dekkers the Netherlands, for their valuable suggestions and comments. The authors also thank Paul Callomon, ANSP Philadelphia, USA, for his helpful translation of the original description of *T. delicatum* from the Japanese and advice on Museum contacts in Japan. For access to material we thank Valda Cantamessa and Uwe Weinreich.

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THE UNCATALOGUED TOWNSVILLE EARTHQUAKE OF 1879: FOUND DOCUMENTED IN THE QUEENSLAND PHILOSOPHICAL SOCIETY MINUTE BOOK

LYNAM, C. J.

The Queensland Philosophical Society (QPS) was the forerunner of the current Royal Society of Queensland. Within the Minute Book of the (QPS) (1865-1883) lies a handwritten entry on a Queensland earthquake that occurred at 7 PM, January 5th, 1879, with an epicentre most likely located west of Townsville (Queensland). That historical document is surprising for its professional and forensic style. The discovery of this 4-page descriptive essay is of note because the earthquake's occurrence is not listed in any of the definitive Australian or international catalogues. This document (attached) represents, I believe, the first scientifically documented macroseismic study of an earthquake with an epicentre in Queensland. We must remember that at this early date, Queensland's Board of Education had barely begun. Technical education is attributed to have started about 1881.

The document represents an early contribution to earthquake engineering, written by a citizen scientist with an eye for scientific observation. It is also early evidence of the ongoing societal value and contribution made by learned societies, and other professional technical societies. Their role continues for encouraging observation and documenting natural phenomena as well as communicating that knowledge and especially maintaining their digital archival collections, thereby increasing our longitudinal knowledge.

Keywords: Queensland earthquakes, macroseismic earthquake intensity, Learned Societies, Queensland Philosophical Society, Royal Society of Queensland

Email: eqservices@telstra.com

DISCUSSION

The author of the earthquake field study in the 1879 Queensland Philosophical Society (QPS) Minute book, in Brisbane, is anonymous. The study is self-revealing as to the author's obvious professional background. I am assuming that the QPS Minute Secretary (see Figure 5), a Mr J Thorpe is the author. I feel further justified in this, by referring to that author's two other publications made in the QPS Transactions (3, p4 pls1-2) and the QPS Proceedings (4, pp28-30), as referenced in F.S Colliver's publication *AN AUTHOR INDEX FOR THE PROCEEDINGS OF THE ROYAL SOCIETY OF QUEENSLAND 1884 -1959, AND THE TRANSACTIONS THE QUEENSLAND PHILOSOPHICAL SOCIETY 1859 -1882*. Both papers are short observational reports on meteorological phenomena.

Of contemporary interest, in researching this paper, I also uncovered what would appear to be evidence of an endemic Queensland government's total lack of interest in physical sciences and geology, even back in 1869, which is much the same 150 years later.

The author of '*A History of the Queensland Philosophical Society and the Royal Society of Queensland from 1859 to 1911*' (E.N. Marks), documents the origins of the QPS and its member's professional activities and contributions, but Marks has not cited this earthquake article, in her definitive work. She does note though, that at the time of writing of the 1879 field report, there was a considerable injection of geological enthusiasm with the visit and "pep-talk"of Australia's most eminent scientist and geologist, Rev. J. E. Tennison-Woods (see Figure 1). A QPS committee meeting occurred in 1879, to change the QPS to the Royal Society of Queensland – a period of expectant change.

Perhaps the intention of the author Thorpe, for making the handwritten QPS earthquake report was to create a proof and publish a later scientific paper? Thorpe himself notes "As it is highly desirable that occurrences of this kind should be placed on record, I have collected the following notes". This is evidence of the scientific ethos, in QPS, at that time.

It is worthy of note that the 1879 earthquake report (see appendix) uses a forensic style of description, relating differing earthquake felt effects to the different geological outcrops, noting "sand blows" and "rocky parts of town". He searches for evidence of other historical earthquake reports and discovers a memory of another earthquake in the Palmer River goldfields. He also notes the areal differences of felt intensity with "not felt" reports from 60 miles away. This is a classic, modern macroseismic study technique. From these descriptions of the public reports of felt intensity, we can calculate that this is a Richter magnitude (ML) of 5 (pers comm Gary Gibson, University of Melbourne). My tentative epicentre information is detailed in Table 1.

It is interesting to comparatively note the difference in written expression with that of the reportage in the quoted local paper, that calls on all types of metaphors to express the earthquake effects. There is a suggestion that the author Thorpe may have shared his knowledge with the local paper.

CONCLUSION

From the table below (Figure 2), that originates from a search of earthquakes by date and that region, on the Geosciences Australia website, we can see (1) that the 1879 earthquake is missing and that (2) felt earthquakes greater than ML 3+ occasionally occur in the nearby hinterland of the Charters Towers – Townsville region, with one in 1913 of even larger magnitude (ML 5.7) and which was more widely reported. There are other epicentres offshore. There were no seismographs in Queensland until 1937. Historical verbal reports are the only evidence.

What is more interesting, is the reason why this 1879 earthquake was not even documented in

In 1871 and in 1876 there were discussions on steps to increase the usefulness of the Society, but no decisions were reached. In November 1878 a Special Meeting was called by Bancroft, Waugh, and Staiger to enable Rev. J. E. Tennison-Woods to meet members. He was one of the most eminent scientists in Australia, a geologist, palaeontologist, and to a lesser extent botanist and zoologist. He gave them a real pep-talk, comparing the activity, finances, and publications of kindred societies in the other colonies and pointing out that they lost a great deal by exchanges. He suggested increasing the membership, seeking a Government grant, prompt publication of papers, and revising the rules. A committee, consisting of Gregory, Nisbet, Bancroft, Waugh, and Thorpe, was formed

FIG. 1. QPS seeks to re-invigorate its activities (p29 Marks).

Magnitude	UTC	Latitude	Longitude	Depth (km)	Location
3.2	25/11/1953 04:31:02	-19.700	147.700	0	
4.5	05/04/1950 19:50:52	-21.100	149.200	33	
5.7	18/12/1913 13:54:00	-20.000	147.000	33	Charters Towers QLD. Magnitude from isoseismal map, MMIII radius
4.5	11/11/1875 10:50:00	-22.000	148.500	30	

FIG. 2. Catalogue (Geosciences Australia) of similar region Earthquakes, 1850-1960.

the recent publication (2012) by McCue (UCQ) in his paper titled Historical Earthquakes in Queensland. Most of the unknown earthquake epicentres McCue publishes are attributed to; "This new information has come about thanks to a courageous initiative of the Australian National Library, making scanned, searchable newspapers publicly available on the internet. These new data and their interpretation are important for better hazard assessments by improving early earthquake details and extending the earthquake database backwards, to better define source zones and lower the magnitude threshold of completeness intervals." The answer is that the QPS documents were not digitally scanned until November 2016, according to a Queensland State Library. The QPS digital reference included a QPS Minute Book cover note- "1879 earthquake of Townsville". My keyword search alert detected it and so I "found" it. Research articles like this one will shed more light on the completeness gaps in our digital knowledge of historic earthquakes, which are mapped in Figure 4 (after Payne).

It is sobering to remember that just over 100 years ago at 4:14 am (EST) on June 7, 1918, Queensland's largest documented earthquake occurred.

> "In Bundaberg, where the tremor was severe, lasting for half a minute, terrified people clung to their rocking beds to prevent themselves from being thrown onto the floor. All clocks in the town stopped. At Banana, 224 km inland, C.S. Bennett was awakened by a violent shaking of his bed. In another house doors opened and shut, and furniture danced around." (Murdoch Wales)

Wales was noting the felt intensities arising from the "Capricorn Bunker Earthquake, ML(I) 6.3; (Also Known As The "Queensland" Earthquake); Largest Known Earthquake In Q'ld; Major Damage; Widespread Effects; Significant Aftershock Sequence." (database entry from Rynn & Weatherley). This earthquake was widely felt over South East Queensland, including Brisbane. They do re-occur!

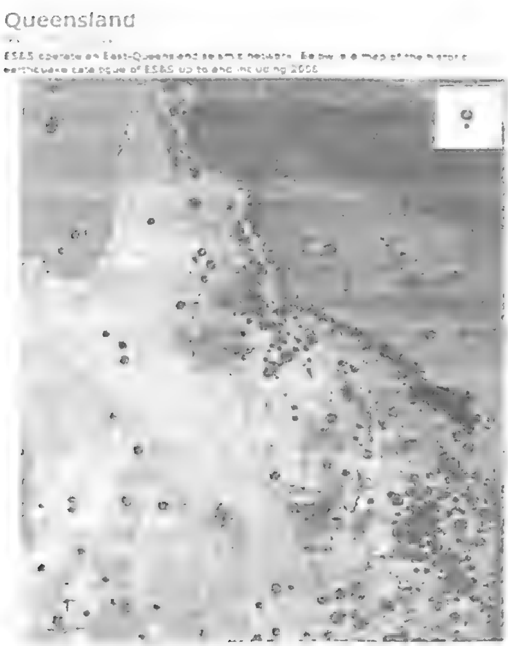

FIG. 3. Catalogued Historical Queensland earthquakes (Payne, 2008).

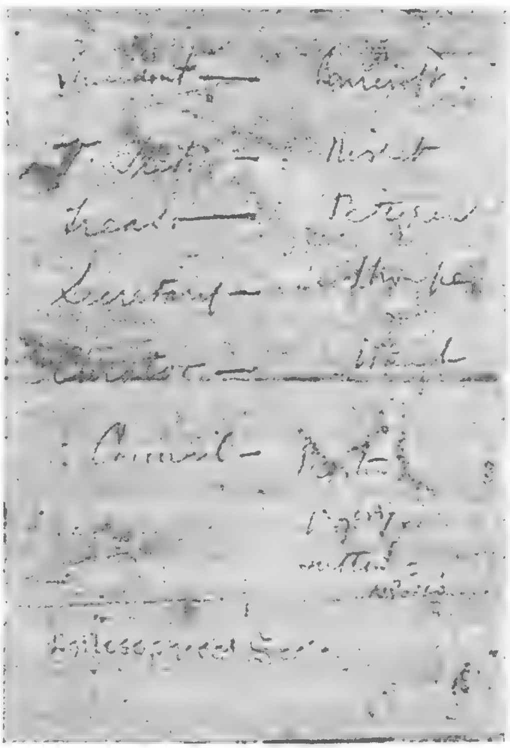

FIG. 4. QPS Office Bearers from 1879 QPS Minute book.

TABLE 1. 1879 Townsville Earthquake tentative catalogue details (Lynam).

Magnitude	UTC	Latitude	Longitude	Depth	Epicentre location
ML (1) 5	0900/5/01/1897	-20.528	145.358	5km	50km S. of Charters Towers

Currently, The University of Queensland's seismograph stations (UQSS) holds a unique collection of similar earthquake macroseismic reports; a collection of over 100 years of scientific data that documents the extent of Queensland earthquake hazard. This unique collection is in jeopardy because of the total lack of interest in seismology within the School of Earth and Environmental Sciences (The University of Queensland) and a lack of professional knowledge of their responsibility under the Queensland Archives Act (1988). It is symptomatic of the total non-interest by the Queensland Government in earthquake hazard. A sad end is looming to a long serving, community and scientific service, for both local and international seismology, previously maintained by academics who read seismology papers to the Royal Society of Queensland. Such scholars as Professors W.H. Bryan, H.C. Richards and F. Whitehouse as well as O. A. Jones were the founders of Queensland's academic research into earthquake hazard and earthquake locations. It is under this shadow that I work, as a volunteer, to catalogue as much of the seismogram and collections archive and deliver it to the Queensland State Archivist, where such public documents belong, now that routine earthquake monitoring, and research are being thwarted. A philanthropic Patron is needed, now, more than ever.

ACKNOWLEDGEMENTS

I wish to attribute my life-long interest in Seismology to the late "Jack" Webb, Director of Seismograph Stations at The University of Queensland. I am very grateful to Dion Weatherly (UQ) for his mentorship and driving interest in seismology. The collegial rapport amongst Australian seismologists, Russ Cuthbertson, Kevin McCue and Gary Gibson has sustained my persistence to meet their expected standards.

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APPENDIX

(Source: Queensland Philosophical Society. Minute book, 5 June 1868-October 1883, 30771/2 John Oxley Library, State Library of Queensland [pages 30771-2-0251b01- 30771-2-0251b04] http://hdl.handle.net/10462/comp/9868)

Author; J. Thorpe (Transcription of handwriting done by C.J. Lynam,2018).

"NOTICE OF AN EARTHQUAKE AT TOWNSVILLE, ON 5TH JANUARY 1879:

> Only a few weeks ago, I made enquiry among some of the oldest settlers in Northern Queensland, regarding the occurrence of earthquakes, & received the unvarying reply that they were quite unknown. Since the shock of 5th January, however I have heard of one shock having been felt on the Palmer River 'since the opening of the goldfields.'
>
> On Sunday the 5th January, exactly at 7PM, everybody in and around Townsville was startled by a sudden shock, which even those to whom the sensation was new, had no difficulty in recognising as an earthquake. As it is highly desirable that occurrences of this kind should be placed on record, I have collected the following notes, which might have been fuller but for the fact that that I was at this time in the midst of preparations of a journey. Having been 'beyond postal communication' for most of the time since, I have not yet heard reports from other quarters.
>
> The intensity and character of this shock varied as might have been expected, with the nature of the ground. In the 'Strand' houses, built on a ridge of blown sand, the shock might be described as a 'thud' or a 'bang', while in the residences on Melton Hill (to), built directly on the porphyry rock, received a 'smash'. The rumbling which preceded the shock 'in' the rocky parts of the town was scarcely heard on the Strand.
>
> In one of the Strand houses (Mr Brand's), a loud noise was heard, like an explosion, and this house received a blow which made it sway and creak in its piles. For a moment it seemed as if a cart had backed violently against the house. The shock came from the west.

In the adjoining house (my own), there was suddenly heard a loud 'bang'. The floor shook, and the piles creaked. A heavy bag of flour on the floor from the height of the ceiling would imitate the sensation very closely. My servants explanation that a horse had run up against the house seemed at first very plausible. The shock travelled from west to east.

In the next house (Mr Morgan's) it seemed as if a heavy piece of furniture was being dragged across the floor. In the fourth house, Mr Philp thought that a heavy dray had come into collision with the back (west) side of the building.

Residents in which may be called the 'rocky' parts of the town have favoured me with the following descriptions of their experience;

#Rev. W. Gray, Melton Hill, (1st) a loud rumbling; (2nd) a smart concussion and report; (3rd) a low rattling noise like the fall of a large mass of brickwork; (4th) the iron of the roof 'screamed'. The blow seemed to come from the South West.

#Dr Geldard, Melton Hill, the top of the tank and the iron roof over a gangway came in smart contact, making a very distinct metallic ring.

#English Church, Melton Hill, rumbling noise ending in sharp blow and report. The sound distinctly travelled from the organ to the corner of the building opposite (south west to North east):

#Mr Bevan, Melton Hill Smart blow and report. Dishes rattled, and iron roof grated. Shock seemed to come from the west. Thought at first it was a dynamite explosion.

In addition to several other cases (of) dishes rattling, I heard of a box of type in a printing office been blown over and of a boy on flat behind Flinders Street having been thrown off his legs. Two gentlemen enjoying the cool of the evening seated on a log afloat in Ross creek, felt their seat vibrate with the agitation of the water.

The shock was felt at Mount Louisa (5 miles south of Townsville) with equal intensity. I have since ascertained that it was not felt Bowen nor at Normandy Diggings (60 miles South of Bowen)."

(Author note; Thorpe then quotes the Northern Standard, January 7th,(1879) newspaper report which is now transcribed from that source; https://trove.nla.gov.au/newspaper/article/169533951))

AN EARTHQUAKE IN TOWNSVILLE.
So few events of a very startling nature to occur in our usually quiet town, that an earthquake is an occurrence of such a sensational character as to excite more than ordinary attention among our townspeople. Many have never experienced the sensation before, and not a few of us — particularly the feminine portion of our community— would not care how far the visit of this phenomenon of nature are apart. Its destructive power is so well known, and its occurrence been marked with such disastrous circumstances in other parts of the world, that we feel naturally timid at the bare mention of it, but to actually have to realise the effects of it never for a moment occurred to us. It would seem as if the bowels of the earth in some way desired to give notice of their existence and were jealous of allowing the atmospheric elements to have it all their own way—as indeed for the last few days they have been doing, in the shape of thunder, lightning, gales of wind, and heavy falls of rain.

Sunday evening last about 7 o'clock the town was visited by a shock from an earthquake. Many residents could hear the rumbling sound some seconds before it reached the town itself, and it was by many mistaken for thunder, and others for an approaching storm, but on its passing under the town there was no mistake about it. The earth vibrated perceptibly, the houses shook, furniture, china, and ornaments rattled — and human beings underwent a not very enviable sensation. Some who were sitting out of doors felt the shock more than those who happened to be in their houses at the time and described the feeling as very similar to that of a shock from a galvanic battery, only in a much milder form. The shock lasted about sixteen seconds and was very generally felt in all parts of the town. About five miles out of town, at Mount Louisa, a gentleman residing there, described the shock, as sharp, shaking everything in the place; he also states it was accompanied by a loud report. The readings of the Barometer and Thermometer were accurately taken at the time by a gentleman who is in the habit of taking the readings of both instruments regularly every day, and to whom we are indebted for the following information: —

The following are the readings of the standard Barometer and Thermometer on Sunday last at 2 p.m., and immediately after the shock of earthquake at 7 p.m.: At 2 p.m.— Barometer, 29.712; Thermometer, 91°— being the second lowest reading of the Barometer, and the highest reading of the Thermometer during the last three months. At 7p.m. — Immediately after the shock Barometer, 29.760; Thermometer, 86°. We might mention that the lowest reading of the Barometer, during the last three months was yesterday, January the 6th, at 2 p.m., being 29.688. All the above readings were taken in the shade. Northern Standard, January 7 (1979).

A STEWARDSHIP INCENTIVES SCHEME FOR QUEENSLAND'S PASTORAL LANDS

EDWARDS, G.

The pastoral industry and the natural systems on which it relies have been subject of a vast body of published literature. Yet evidence is that the environmental condition and profitability of Queensland's pastoral enterprises, speaking generally, continue to deteriorate. The paper argues that markets for food and fibre are disconnected from the cost of production and insufficient money is being invested in maintaining the stock of natural capital. Market forces do not reimburse pastoralists adequately for the cost of producing commodities sustainably, let alone for the cost of regenerating landscapes that need restoration. The imbalance cannot be resolved within a conventional market conceptual framework. The solution is to reimburse landholders for producing the ecosystem services that support human life and drive landscape function – primarily public goods – in a parallel system of payments.

INTRODUCTION

In reviewing the literature on the management of Queensland's pastoral zone, one stands in awe at the depth of scholarship displayed by scientists and others who have committed their knowledge to paper over at least the past five decades. Not least of the available sources are The Royal Society of Queensland's own publications *The Mulga Lands*, 1986, of 160 pages, and *Landscape Health of Queensland*, 2002, of 258 pages, edited and co-edited by Past Presidents Paul Sattler and Dr Julia Playford respectively; and the regular issues of the *Proceedings of the Royal Society of Queensland*. Scientific knowledge has far outstripped the capacity of the policy community to apply that knowledge towards a sustainable future for the pastoral zone. What further summary of scientists' collective knowledge is needed?

Despite this wealth of authoritative knowledge, one looks in vain for any adequately funded forum to translate the enormous body of available scientific information into property-specific terms for landholders, or policy-specific terms for parliamentarians and other thought leaders as contemporary debates unfold.

Deriving from evidence of both poor land condition and systemic financial hardship in Queensland's rangelands, the purpose of this Opinion Piece is to outline a model for reimbursing Queensland's pastoral landholders in return for a refreshed contribution to regenerating and maintaining these landscapes.

Even if these twin claims of systemic unsustainability are disputed or are considered manageable, climate change, with unknown and probably widely varying consequences across the inland, is coming; and this will force comprehensive adjustment upon all stakeholders. No model of public or private land management to prepare for this emerging reality is known to exist.

The paper focuses on Queensland's rangelands – the broadacre unimproved pastures of the inland where grazing is the primary land-use – under the management of 'graziers' or 'pastoralists'. 'Landholders' are managers of property under freehold or leasehold tenure. 'Pastoralist' emphasises animal production; 'landholder' emphasises custodianship of property.

This paper is a summary of a longer web-published work *From Red to Black to Green* edited by the present author. The longer work establishes a theoretical foundation for the arguments here and includes more than 10 pages of supporting references.

EVIDENCE

Scientific evidence from the periodic State of the Environment reports, state and national, is that the land condition of Queensland's pastoral estate is suboptimal and deteriorating. The pressure of grazing by stock and kangaroos is not being relieved sufficiently in the periods between droughts to maintain the resilience of these landscapes. Neglect of catchment health costs the community dearly, though the effects are delayed and often indirect.

This evidence parallels economic evidence that the financial health of Queensland's pastoral industry is also suboptimal and deteriorating (Holmes 2015,

Katter 2016, Rees 2015). A high proportion of rural properties carry financial debt that cannot be serviced through income earned by producing commodities of food and fibre. The prices that farmers receive for many commodities are capped by international prices set in US dollars, but their costs are set in Australian currency and rise according to the cost of living so they have no ceiling. Primary producers are reduced to being price takers squeezed by competition between middlemen and retailers within Australia, and yoked internationally to a national bipartisan commitment to nearly unconditional free trade and free foreign investment.

In pursuing competition policy since the National Competition Policy reforms of 1995, Australian governments have deliberately preferenced the interests of consumers in cheap food products over the interests of its producers in receiving a fair return for their labour and investment and for their reduction of 'co-benefits' and ecosystem services. Producers instead have been lectured to reduce costs to remain competitive. 'Reducing costs' for farmers means investing less in the regeneration of the natural capital asset on which their enterprises are based, as these expenditures can be deferred and their decline is not always apparent.

The resultant of these forces means that graziers in Queensland's pastoral zone typically cannot look to market forces to reimburse them adequately for the cost of producing commodities sustainably, let alone for the cost of regenerating landscapes that need rest and restoration. After a run of dry years, many graziers have nothing left in reserve. This is not to deny that some grazing businesses are reliably profitable, use advanced technology, are managed by optimistic, energetic and enterprising operators and are actively working towards sustainability. In the unimproved pastoral rangelands as defined here, however, this does not describe the typical enterprise.

Indirect evidence of rural financial distress appears in statistics of rural employment. The latest update from the Queensland Government Statistician's Office (QGSO 2018) has a nominal youth unemployment rate in outback Queensland of 39.5%. This is a Depression-era statistic.

The State's broad acre pastoralism is unsustainable in all dimensions – *environmental*, *economic*, *socio-cultural* and *institutional*. How can a crisis develop on all fronts without adequate policy response? The answer lies in the disaggregation of the capacities of all the stakeholders involved. The indicators of *environmental* distress are well known to scientists and conservation groups, but the conservative media demonises experts who present this evidence; and opinion leaders in politics lack the scientific literacy to recognise the urgency (Edwards 2014b). Indicators of *financial* distress are absorbed by private debt which can pile up behind a privacy screen and be attributed to personal business incompetence. The main indicator of *macroeconomic* distress, gross domestic product, GDP, is inadequate for tracking the rundown of built and natural capital (Cobb et al 1995). *Socio-cultural* distress surfaces in the police, health, Centrelink and prisons budgets where it is attributed to personal failure and in unemployment statistics where it is attributed to malingering. Finally, distress in the *public institutions* that grapple with management of pastoral lands, notably the Landcare and natural resource management (NRM) groups, is masked by the valiant efforts of volunteers who burn themselves out trying to cope with stop-start grant funding which is never adequate to confront the root causes of unsustainability.

A POSSIBLE SOLUTION

Here is a solution.

Most graziers (excluding feedlotters) are managing not just a food factory but a complex natural system of land, water, atmosphere, vegetation and animals. If managed protectively, it will produce not only a marketable commodity but what is known as 'ecosystem services' – fresh air, clean water, carbon storage, wildlife and other components of humans' life-support systems.

Landholders running grazing enterprises are usually not reimbursed for managing these essential elements of our habitat as they are considered to be free gifts of nature. But it costs money, time and effort to keep these systems in good condition – by preventing erosion, controlling weeds and vermin, repairing previous degradation, maintaining ground cover. If landholders were paid to produce these ecosystem services, they could derive a reliable source of income year in year out, and most notably at times when they can't produce commodities because of drought, fire or flood. Such payments would not be handouts or subsidies: they would be payments for tangible products that landholders generate, now usually without recompense.

The arguments for and against using taxpayers' funds to subsidise distressed pastoral families are well known. On the one hand, the general public has a deep well of sympathy for rural landholders, who are the custodians of most of our State's land surface, produce our food and uphold our cultural 'bush' traditions.

On the other hand, there is an element of injustice in offering bailouts to pastoralists yet not for example to city-based manufacturers who are likewise driven to failure by policy settings beyond their control, like free trade.

Economists near-unanimously oppose subsidies because they are adamant that businesses should stand or fall on the basis of their commercial success without intervention by governments. However, the markets in agricultural commodities don't conform to textbook theories of perfect commercial competition. The production markets, the commodity markets and the land asset markets are all products of policy; and in any case are disconnected from each other.

A number of concepts must be unpicked to establish a firm logical foundation for any remedial action. An explanation of 'stewardship' can be found in Finlay (2014) and of property rights in Edwards (2003). Landholders enjoy certain rights conveyed by the title – leasehold or freehold – that permits occupation, but these are matched by a duty of care and other obligations to the society that legitimises and recognises their title. The common law duty of care not to harm neighbours' property is supplemented on all tenures by duties not to cause environmental harm or damage "cultural heritage" and on state leasehold (more than sixty percent of Queensland) by an additional duty of care to the land.

Clarifying what the 'duty of care' means on a particular property is a precondition for quantifying the environmental services which might justify reimbursement to landholders. This is analogous to the dilemma within Landcare as to whether taxpayers' funds should be disbursed to private commercial businesses, a dilemma unresolved after 35 years of Landcare. In principle, it is easy to argue that no scheme should pay landholders to abide by the law. In practice, 'the law' includes the common law not to cause any damage to anyone else's property and the statute law not to cause environmental harm. These common law and statutory duties are not applied literally and strictly. If indeed they were so applied, almost no landholder could comply. The intersection between free market forces and the general environmental duty sets the canvas for an impasse for which there is no current policy solution.

It is unfair to expect graziers to manage to a standard of environmental sustainability that cannot practicably be achieved through environment-blind market forces alone. This gives theoretical support for some extra-market payment in return for a contracted commitment to upgrade the standard of land management.

Further, over State leasehold land, the State as landlord has a largely unrecognised and rarely exercised tacit obligation to periodically make good the 'fair wear and tear' that is a normal consequence of tenants' occupation. This strengthens the case for some form of public contribution to regenerating this proportion of the rural landscape.

The economic value added by investing taxpayers' or public funds in land restoration can be shown to typically far exceed the economic benefits of, say, large transport infrastructure projects, at present a major sink for public funds (Elaurant & Louise 2015). Public budgets are paying the cost for suboptimal land management, but this happens by disconnected stop-start programs such as Great Barrier Reef rescue and the repair of silted up rural infrastructure rather than through more efficient preventative programs.

Two major challenges bearing upon pastoralists make a brand-new approach to rural sustainability imperative: climate change and unserviceable rural debt. Both are now pressing themselves into public and rural consciousness. Both are already well recognised in the rural community but are yet to gain traction with policy makers. The proposed scheme, being an extra-market payment, cannot overcome the backlog of legacy rural debt, but can make a modest contribution to strengthening the resilience of Queensland pastoralists in facing future challenges.

IMPLEMENTING THE CONCEPT

An extra-market incentives scheme does not need to be administered by governments. Queensland is covered by 12 regional community catchment bodies that have already been accredited to administer state and federal grant programs.

Precedents are available. In 2008 South West Natural Resource Management, the regional NRM body based

at Charleville, successfully ran a pilot stewardship program in the pastoral mulga lands (Edwards 2014a). The objective was to reduce grazing pressure during the critical period when drought-breaking rains arrive and native pastures need time to regenerate. In return for regular monthly payments, participating landholders surrendered their right to graze stock for a defined period. They retained their sovereignty and responsibility for every other aspect of their enterprise. More than 10 per cent of the pastoralists within the study area expressed interest in the scheme. Participants were chosen by tender. The public interest was to be served by improving the health of the catchment – less erosion, more infiltration of rain, more regrowth of native tussock grasses.

Any payment for ecosystem services logically should be contributed by the beneficiaries, which includes all Queenslanders (so can be procured via general taxation) or consumers of food and fibre (so can be procured by a levy on consumption). There are several logical sources of funds for a stewardship scheme. First, the payments could be structured around carbon management. Carbon-rich soils are more productive, erode less and make more efficient use of rainfall when it comes. The Queensland Government's Land Restoration Fund announced in 2017 seems to be proposing to tap into carbon credits as the main financial engine of land restoration. The proposal is problematic, as it amounts to hypothecating a source of funds generated in the federal arena by monetising abstract promises towards a different purpose within the Queensland Government's arena of jurisdiction. Also, as Lauder (2018) has explained, it is the more difficult-to-measure carbon flows that drive landscape health and hence sustainable productivity, not the measurable carbon stocks that underpin carbon credits.

Second, payments could be toggled with Centrelink entitlements. A back-of-envelope calculation suggests the cost of an effective stewardship program might not be much greater than the welfare outgoings now distributed to support distressed families in inland Australia. And of course, stewardship payments have dignity – they are real reimbursements for real production, not handouts. Farmers understand stewardship (Finlay 2014).

Third, a 'sustainability levy' of a few cents could be added to the price of a litre of petrol, or a half percent to the top tier of income tax. Fourth, a simple line item could be created in the state budget, just as there is for police, education and health.

Several procedural steps must be taken before payments can be made under a stewardship scheme of this kind. The first is to negotiate a bipartisan commitment to support a scheme for twenty years. The second is to settle on a source of secure recurrent funding. The third is to grant a mandate to a coordinating agent that has the confidence of the rural community to administer the scheme. Rural trust in the Queensland Government as a benevolent agent has been so damaged during the era of downsizing and restructures (and latterly, arguments over vegetation management) that this coordinator arguably best lies outside government. The regional natural resource management bodies are the most suitable candidates in sight to implement a scheme, within a policy framework endorsed by the state.

A fourth procedural step is multilateral, consultative landscape planning, overseen by the coordinator, that translates scientific, practical, cultural and policy knowledge into guidelines for each catchment and sets the context for property-scale management planning that in turn can specify desired practical works. The fifth is a property-specific voluntary accreditation scheme that negotiates commitments, specifies standards to be reached and calculates payments.

Finally, a strong research capability must be re-established. Scientific and policy research is required. into the implications of climate change for each district, the meaning of duty of care, carbon sequestration as an economic driver, carbon flows as a driver of paddock resilience and how sustainability in all its dimensions can be achieved. Given that the rangelands cover most of the continent, rangeland management should be embedded in the training of all agriculturalists and veterinarians.

A stewardship scheme of the kind outlined would depart from orthodox remedies for rural distress in many ways. It would not be a subsidy for production, which can be disconnected from the health of the natural asset base and would be problematic for Australia's compliance with the World Trade Organisation's disciplines. It would not require compulsory property management planning, as there is a large cohort of landholders, probably the majority, who would be willing to conduct property management planning if they could receive respect and reward as

a consequence. Access to graziers' books of account as required by the authorities or banks for various rural debt or loan subsidies would not be necessary. It would not be a form of non-reciprocated welfare. A grant could be secured on landholders' title by one of the available covenant-type instruments, such as profit à prendre, but this seems unnecessary given the small sums involved and given that payments would be periodic and subject to performance each term. Property rights would not be infringed and controversy over vegetation clearing sidestepped as that would continue to be dealt with under law.

As noted above, payment should not be made for site works that would or should be fulfilled otherwise under landholders' duty of care. This is a risk that according to Blakers & Considine (2016) bedevils the Commonwealth's Direct Action plan. The risk can be mitigated by quantifying the ecosystem services that each property would contract to produce or the cost of works. If, as claimed here, healthy and sustainable animal production depends upon healthy landscape management, then landholders who participate might reap improved commercial productivity and hence profitability. Procedural guidelines would need to be structured to avoid double dipping, but increased profitability is simply another form of reimbursement not requiring intermediation.

Assuming that an incentive scheme finds favour in principle, there are many details of implementation that could cause it to fail. This paper does not sketch an in-depth-plan for implementation, for reasons explained in a parallel paper on feasible paths submitted for publication in this edition of the *Proceedings*. Once a coordinator is invested with sufficient authority, that agent can assemble the other capacities and resources needed to fulfil a program. Here, I nominate the regional catchment bodies as the most appropriate coordinators. Their mandate would assign to them the task of establishing appropriate drivers, capacities and accountability measures to bring the scheme into a disciplined conclusion.

Pastoralists should not be the target of blame for the current poor condition of pastoral Queensland. The scheme honours the role of pastoralist landholders as producers of both commercial and non-market products and services. In any case, even if all their previous management were faultless, global warming for which they cannot be blamed will force a comprehensive rethink of their pasture management and business models. Nor should governments of either major persuasion be blamed, for the current canvas is a resultant of many forces and events over more than a century. Rather, it challenges governments to solve the twin problem of poor land condition and economic unviability that have resulted from a range of disparate forces using contemporary knowledge and powers.

A CRITICAL REVIEW

Some shortcomings in the analysis in this paper and in the longer work from which it is derived should be acknowledged. First, the argument in favour of an extra-market payment rests upon the observation that broad acre pastoralism is, on average, unprofitable or only marginally profitable. If a graziers of average competence and average debt load can anticipate a profitable business, then the argument for relying upon regulation rather than incentive payments to enforce improve standards of management is more compelling. Evidence of profitability is difficult to establish. Rising levels of rural debt are taken in this paper as a proxy for evidence of marginal viability, but this question deserves more thorough treatment.

Second, not all socio-economic difficulties within the pastoral industries and rural communities are the direct result of market forces. Social and employment opportunities draw people from the outback to the cities. Evidence is that subsidies and payments for environmental services have not prevented the hollowing out of rural communities in other developed countries. 'Pull' as well as 'push' factors operate. The unavailability of labour to invest in rural land management may remain a challenge to better land management, even if landlords have adequate funds to offer. Drought and climate change will further diminish the appeal of an outback lifestyle.

Third, the paper lacks a review of the effects of schemes in other jurisdictions by which incentives have been paid to landholders. A comparative analysis of the consequences for landscape management of the Common Agricultural Policy of the European Union with the production-orientated subsidies that feature in US farm policy (USDA 2018) would be valuable.

Fourth, realpolitik suggests that powerful institutional obstacles would need to be overcome to establish a stewardship payment scheme: notably, an aversion by governments to long-term funding commitments; a lack of trust in government by rural producers; the

vulnerability of public funding to changes in policy; and the instability evident in policy settings related to carbon emissions and climate change. The paper is dismissive of using payments for carbon sequestration to drive landscape improvement, but schemes to funnel such payments into rural industry are a current reality and hold out more hope in the short term of driving improvement.

Finally, contrary arguments advocating reliance on market forces or avoiding costs to government budgets overlook the vital role farms play in maintaining the health of our land. A healthy countryside has both private and public benefits. Even if we assume that market forces will take adequate care of the private or commercial aspects of agricultural production (and this is debatable), by definition market forces will ignore the non-commercial production.

PAST SCHOLARSHIP AS A GUIDE TO FUTURE STRATEGY

The "Conclusions" of the Mulga Lands Symposium held in November 1985 (Sattler 1986) bear repeating. A modern task force might have considerable difficulty improving on these as a contemporary statement of aspirations for Queensland's pastoral rangelands generally.

"Specifically it was concluded that:

- Protection of the natural resource to achieve sustained use be the paramount consideration of government and industry land stewardship.
- A land use planning framework be developed for balanced and sustained use of the mulga lands.
- Greater effort be made to facilitate extension of management research information to landholders to assist in management.
- Nature conservation, the establishment of national parks and the promotion of tourism be planned as legitimate uses within the mulga lands.
- Federal Government financial incentives were essential to achieve objectives of the National Conservation Strategy. Incentives should encourage sustained land use and implementation of nature conservation strategies.
- Land administration, including property size, tenure review, and lease conditions should reflect land care and stewardship as its basis.
- Rural stock routes represent an important land resource for multiple land use including nature conservation and recreation. Policies should be developed for their long-term retention and protection.
- Drought relief subsidies do not encourage sympathetic land management and should be reviewed so as to provide an incentive for good management.
- Land zoning and clearing guidelines be established to protect marginal and fragile lands.
- Land care and stewardship become part of school curricula, the basis of extension services, and rangeland management be introduced into university and college courses."

CONCLUSIONS

Summarising more generally, it can be said with confidence that farmers without adequate discretionary income cannot be expected to tend for those elements of their production system that don't return a profit. If the price system doesn't return adequate discretionary income, then a system of direct payments is required. Otherwise the soils and rivers and pastures of our state will continue to suffer, along with the well-being of the people who manage them on our behalf.

Society elects representatives and pays taxes to enable governments to solve collective problems on its behalf. Despite overwhelming scientific consensus developed over more than 30 years, this twin problem of financial and environmental sustainability has not been solved and it is the duty of governments to solve it.

The scientific and financial evidence is clear that the current economic model by which pastoralists in the rangelands are reimbursed through market forces is unsustainable, that it is incapable of accommodating rapidly advancing climate change, that it is imposing heavy unfunded liabilities on the future economy and that a new approach is both vital and urgent.

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AUTHOR PROFILE

Dr Geoff Edwards B.Sc.(Hons.); M.Pub.Ad.; PhD; GAICD is qualified in ecological science and public policy. He worked in parks and Crown land administration in Victoria and Papua New Guinea. He was a local government Councillor for six years and Shire President in Victoria. From 1991-2006 he served in Queensland's Department of Lands/Natural Resources as Manager, Land and Regional Planning, with responsibilities for a range of aspects of land policy. After a stint in 2007-8 as Chief Executive Officer of South West NRM Ltd based in Charleville, he retired from the Department of Mines and Energy in 2011. In June 2013 he was elected as President of The Royal Society of Queensland.

ANNUAL REPORT, ROYAL SOCIETY OF QUEENSLAND, 2017 – 2018

OVERVIEW

This report covers the period from 1 October 2017 to 10 October 2018. The Society has again had an active year with several inspiring events as well as timely publication of our journal, *Proceedings of the Royal Society of Queensland.*

The challenges facing science in particular and evidence-led enquiry in general look very similar to those that the Council reported to the membership last year, and if anything, have worsened during the year as climate change progressed and our political leaders stumbled over an adequate response.

Council is proud that during the year, it has again been able to publish first-rate material in its annual *Proceedings of the Royal Society of Queensland*, now 134 years old. This is arguably the bedrock activity that entitles the Society to speak on behalf of the scientific community. In volume 122, the Society with its authors and reviewers published highly competent papers on matters with considerable economic and political significance: such as the decline of the lungfish, the remediation of abandoned mine sites, the decline of honeybees and the prospect of using oyster banks to clear polluted seawaters. All these subjects deserve serious and focused attention by decision-makers. Yet clearly, while releasing original knowledge into the Australian and global knowledge arena is necessary, it is not sufficient to achieve remedial action.

Council believes that amongst its membership and the broader network of researchers and thinkers of which it is a part, there is a latent capacity to summarise and translate technical knowledge into terms that broader society and decision-makers can understand and use to guide action. What is lacking is the financial resources to assemble this capacity and to bring it into public attention. The Society relies almost entirely on membership fees which are insufficient even to cover the cost of printing the *Proceedings*, so the Society is drawing down its reserves. This is unsustainable.

There is an emerging view amongst the office bearers that during the next 12 months, Council should invest whatever discretionary time it can muster towards seeking philanthropy or sponsorship to allow it to release the talents and insights of its network of knowledgeable people.

CORPORATE AFFAIRS

MEMBERSHIP

As of 10 October 2018, the Society has 96 fully paid up members with another 45 due for renewal. There are six Honorary Life Members.

A memorial service for long-standing member Dr HWB 'Don' Eastwell was held on 23rd April 2018 at Sumner Park and attended by member and family friend James Hansen on behalf of the Society. Dr Eastwell served on the Editorial Board for a number of years.

Council member Revel Pointon was awarded the 2018 Mahla Pearlman Award for the Australian Young Environmental Lawyer of the Year by the Law Council of Australia. Revel Pointon is a lawyer specialising in law and policy reform with community legal centre, the Environmental Defenders Office, Queensland. Revel holds a Bachelor of Laws and Bachelor of Environmental Management from the University of Queensland, a Masters from KU Leuven, Belgium and a Graduate Certificate in Policy and Government from QUT.

Professor Sean Ulm was awarded the Rhys Jones Medal for Outstanding Contribution to Australian Archaeology by the Australian Archaeological Association, its highest award. The medal is presented annually to an individual who has made an outstanding and sustained contribution to the field. Prof Ulm, a Fellow of the Australian Academy of the Humanities, is an archaeologist whose research is at the forefront of human-environmental studies in Australian archaeology. He works closely with Traditional Owners and with researchers in cognate disciplines to build holistic and polyvocal explanations of the archaeological record.

Corinne Unger was among a distinguished list of contributors to the Australasian Institute of Mining and Metallurgy and minerals industry recognised in the 2018 AusIMM Awards and won an award for Professional Excellence. Ms Unger was nominated by the Community and Environment Society of AusIMM for various committee roles and for mine rehabilitation and closure and abandoned mines over the years. She was previously the inaugural chair of the Society's Committee.

On 28 September the President Dr Geoff Edwards was appointed as Adjunct Professor in the Centre for Governance and Public Policy, Griffith University.

Early in October 2018 Emeritus Professor Angela Arthington, a member of the Society's Council, was advised that she is the 2018 recipient of the Australian Society for Limnology Medal, its highest award. The medal is presented in recognition of significant contributions to freshwater science. Prof Arthington has published widely on river and fish ecology, environmental flows, aquatic biodiversity and conservation biology. She has over 280 publications and almost 20,000 citations to her credit. Angela was a member of the academic staff at Griffith University from 1976 until 2011 and has supervised 35 students at the honours, masters and PhD level. Many of her students have gone on to make a significant contribution to freshwater ecology through employment in CSIRO, local and State Government, as private consultants, in business and in University faculty positions.

ROYAL SOCIETY OF QUEENSLAND COUNCIL

The Council elected at the Annual General Meeting comprised Angela Arthington, Geoff Edwards as President, Ross Hynes as Assistant Secretary, Arthur Needham as Secretary/Treasurer, Barry Pollock as Editor, Nita Valerie Sharp, and Craig Walton as Immediate Past President. During the year Revel Pointon and Paul Bell were added by resolution of Council, in accordance with the Constitution, on 7 December 2017 and 20 June 2018 respectively.

One meeting of Council was held, on 23 June 2018. The vast bulk of issues are debated via email traffic.

Regrettably Secretary Dr Arthur Needham contracted a debilitating illness while overseas early in 2018. The incapacity recurred several times rendering him unable to fully discharge the functions of the office. Other members of Council filled in. Prior to his incapacity however he was able to restructure the Society's bank accounts to comply with new regulations.

FINANCES

A generous donation was received towards the running costs of the Society. Another special donation was received to establish a website for the Queensland Science Network.

LIBRARY

Honorary Librarian Meg Lloyd has continued to curate the Society's library of some 20,000 volumes housed at the Queensland Museum. Members enjoy free access to the Society's library, by appointment with Ms Lloyd.

MEMBERSHIP ROLL

At its meeting on 23 June, Council resolved to transition from a manually updated roll kept in fine form for many years by our former Secretary Dr Ben Lawson in an Excel spreadsheet, to a digital roll. This will assist members in renewing their membership by issuing automated reminders, but it requires members to allocate a password to themselves. Regrettably, the digital portal went live and registration was attempted by several members before guidelines on how to register passwords were distributed. This has left a workload to contact each of those members and rationalise their entries.

Mrs Pamela Lauder was engaged to bring the membership roll up to date and to transfer the manual records to the digital roll.

In September member Tony Van Der Ark volunteered to maintain the Membership Roll. The role includes contacting those members whose memberships have expired, to clarify their intentions and to guide them in renewing online. Mr Van Der Ark's ongoing role will also include connecting members to other members with similar interests.

ROYAL SOCIETY OF QUEENSLAND ANNUAL GENERAL MEETING – 22 NOVEMBER 2017

The Annual General Meeting of the Society was held in the Community Meeting room of the Brisbane City Council, Brisbane Square, Adelaide Street.

We were privileged to hear member Mr Robert Whyte as guest speaker on the theme: "From Fear to Fascination – Learning to Love Spiders". "Much maligned and misunderstood, the spiders of Australia are among some of the most amazing creatures on the planet." Mr Whyte's interests include arachnology, habitat restoration, biodiversity, species discovery and macrophotography. He tabled copies of his newly released publication *A Field Guide to Spiders of Australia*, co-authored with Greg Anderson, including more than 1300 colour photographs and covering 836 species.

The AGM resolved to hold a special meeting as soon as possible to determine priorities for the next 12 months. Members expressed concern that the Society had undertaken a work program in 2017 that was more ambitious than its administrative core was capable of supporting. That meeting was held on 4 December.

The AGM resolved that urgent steps should be taken to secure support for the Honorary Editor and President. Support for the Editor was secured, though belatedly, in June 2018 with the offer of Dr Paul Bell to serve as Assistant Editor.

A support team for the President was achieved early in the year, though was more diffuse and unannounced. During the year, the President called on half a dozen members several times for advice and assistance. These have been experienced members, ever-ready to respond to emails and ever-ready to attend meetings. These members no doubt are unaware that they have been members of a "team", but the value of their mature judgement has been invaluable and has been pivotal to the ability of the President and indirectly the Council to make prudent decisions and to keep the Society faithful to its mission.

Further, a number of these members have been conspicuous at different meetings, attesting to their ability to apply scientific method to a range of different subjects. The depth of capacity that this brings to the Society in speaking on behalf of the scientific community is difficult to exaggerate.

STRATEGY PLANNING MEETING – 4 DECEMBER

A planning meeting was held in a State Library room. The meeting identified four priorities to be the focus of our attention in 2018 and these were subsequently endorsed by Council:

1. Publishing peer-reviewed science and evidence, through the *Proceedings* and one or more Special Issues. It was concluded that the Society could not support more than one major symposium per year. However, not every theme warranting a Special Issue would necessarily require a symposium.
2. Develop the Queensland Science Network, initially through the new website.
3. Energise the Research Fund.
4. Renewed outreach to parliamentarians (though not necessarily through meetings in a format like those we held this year).

Items 1, 2 and 3 were pursued according to the strategy. Item 4 was not pursued systematically, although contact was made with the number of present and former parliamentarians, including the Former Parliamentary Members' Association. Late in the reporting year, contact was made with the office of the Speaker of the Legislative Assembly with a view to discussing a training course for newly elected members.

PUBLICATIONS

PROCEEDINGS OF THE ROYAL SOCIETY OF QUEENSLAND

Honorary Editor Dr Barry Pollock oversaw the production of volume 122 of the *Proceedings of the Royal Society of Queensland* and upheld the high standard of this journal of record, the pre-eminent generalist journal for publishing Queensland-specific natural science. Thanks to Mr Rennie Fletcher for type-setting and layout of the journal articles. All papers submitted for publication in the *Proceedings* are subject to review by anonymous referees who are experts in the particular subject area of the submitted paper; except the Presidential Address and the Annual Report which are peer-reviewed by the Council. The labours of the anonymous referees are gratefully acknowledged.

Since 2014, former Secretary Dr Ben Lawson and the President have been labouring to have the *Proceedings* indexed by the international search engine Scopus, a tool of the publishing company Elsevier. Our title was re-accepted for registration in 2015 after ethics statements were approved by Council and published. Remarkably, at year-end, three years later, only a few issues have been indexed and appear on the Scopus website. Early in October 2018, Elsevier advised at long last that they had accepted issues from 1996 to the present for indexing and this should be completed by the time this report appears in print.

SPECIAL ISSUES

Generous offers were received from Prof Roger Kitching, Dr Joseph McDowall and Dr Rene Rossini with Prof Angela Arthington to guest edit Special Issues on the Eungella rainforests, preventative health and the springs of the Great Artesian Basin respectively. Council accepted these offers and preparations are well advanced. Funding to allow print publication of these has not yet been secured. The willingness and optimism of the Guest Editors, authors and reviewers to proceed in the absence of funding is inspiring.

MEMBERS' NEWSLETTERS

Sixteen Newsletters (including intermediate Notifications) were produced during the year, against a target of monthly. The highlight was the offer of member Dr Anne-Marie Smit in May to edit the Newsletters, removing a considerable workload from the President. These Newsletters are privileged to members. It is intended that in due course an archive of them, which provides a useful snapshot into significant contemporary scientific events and trends, will be lodged in the State Library of Queensland. The Society's website also has a facility to lodge the Newsletters and other privileged material on a members-only page, but this capacity has not yet been activated.

EVENTS

BRIEFING AT PARLIAMENT HOUSE – 12 OCTOBER

Following the introductory briefing on the importance of science in May and a briefing by energy expert Alan Pears in September, a second event on electricity was held featuring Prof Simon Bartlett on pumped energy storage. Vigorous discussion ensued.

INEXPENSIVE, RELIABLE, CLEAN: QUEENSLAND'S ELECTRICITY SUPPLY – 20 OCTOBER

A lunchtime forum featuring guest speaker Dr Matthew Stocks from ANU who spoke on pumped storage, followed by a deliberative workshop introduced by guest speaker Prof Simon Bartlett on pumped storage and the need for a high-voltage DC interstate connector was held on Friday 20 October, 2017, at 111 George St Brisbane.

Arising from the intelligence presented at this workshop and the previous one on 8 September, a summary submission was prepared and presented to the Department of Energy and Water Supply on 2 January 2018. This submission was subsequently posted on the Society's website and outlines a number of principles that might guide the Queensland Government to reform its electricity supply regime. The Department contributed an amount of $2500 towards expenses and the shortfall was made up by an Engaging Science grant from the Office of the Queensland Chief Scientist.

The Society is grateful to the speakers for the generosity of their time that made a success of these events.

EVIDENCE-LED POLICY FOR DECISION-MAKERS — 21 NOVEMBER

A one day professional development seminar aimed at people who have no tertiary level background in science was held on 21 November in the Hotel George Williams. The program intended to give a rounded explanation of the history of science, scientific method, science in policy, basic scientific principles, limits to growth and a few specific subjects such as climate change. A fee was charged and, supplemented by the Engaging Science grant mentioned elsewhere, just covered costs. Several members contributed generously of their time. Certificates were presented by representatives of the Office of the Queensland Chief Scientist.

POLICY TOOLKIT – 13 APRIL

Feedback from participants indicated that they would have liked the presented material brought together into a "Policy Toolkit". The President assisted by a number of members, notably Dr Brendan Markey Towler, subsequently developed such a summary focusing on the public interest as the pre-eminent objective of policy. This was exposed at a workshop held in 111 George Street and subsequently refined and sent to all attendees of the 21 November event. This paper has not been released publicly as it is considered to be source material for other initiatives in due course.

PREVENTATIVE HEALTH – 26 MARCH, 9 AUGUST

After one of the firm's partners attended an electricity Forum and was impressed by the standard of debate, international consulting firm PricewaterhouseCoopers offered to sponsor three brainstorm type workshops in 2018 at their city premises on the theme of 'preconditions of well-being':
chronic disease especially obesity (26 March);
youth disadvantage (9 August);
health in Indigenous communities (date to be fixed).

In each case, the presentations would focus on mustering evidence from science – the natural sciences, the biomedical sciences and the social sciences – as to the preconditions of personal dysfunction and conversely personal well-being. In each case, the objective would be to produce peer-reviewable articles that could build up in due course to a Special Issue of the *Proceedings*.

The Society records with gratitude the willingness of Prof Robyn McDermott and Dr Malcolm McDonald

and several supporting panellists to give generously of their time to present at the first two events. At reporting year-end, a model of preventative health bridging disciplines, sectors, levels of government and partisan ideologies is well advanced and on track to be completed by the end of 2018.

STEWARDSHIP INCENTIVES FOR THE PASTORAL ZONE – 28 MAY

At a well-attended forum and brainstorm sponsored by NRM Regions Queensland, the President launched a substantive report *From Red to Black to Green* that he had edited with the contributions of members Chris Kahler, Heather Douglas, Michael Gutteridge and Alan Lauder. Council determined that this Discussion Paper should be published on the web with a view to seeking critical feedback. Council invited the President to submit a summary of the report for peer review and publication in *Proceedings* 123.

This launch event was supplemented on 6 July by a small round table with a few members and external experts to discuss how to take this agenda forward.

Coincidently, after the 2017 election, the Queensland Government announced that it would establish a Land Restoration Fund to funnel money from investors seeking carbon credits into carbon sequestration and co-benefits in rural Queensland. This new initiative closely resembles the stewardship incentives proposal in the Discussion Paper, differing primarily in the proposed source of funds (carbon investment and taxation respectively). The Society resolved to collaborate with peak farming body AgForce and NRM Regions Queensland, the peak body for the regional natural resource management groups, to offer to assemble technical knowledge from scientists and practitioners for submission to the Fund's secretariat. At year-end, these representations had not borne fruit.

CALL FOR APPLICATIONS FOR THE RESEARCH FUND – 5 JUNE

At a joint event sponsored by University of Queensland's Centre for Biodiversity and Conservation Science and partnered with the Brisbane Society for Conservation Biology, Prof Trevor Clifford, Life Member, launched the inaugural call for applications for the Research Fund at an event at the University's Global Change Institute. The occasion also served as a celebration of 70 years' active research by Prof Clifford and his colleague Prof Ray Specht, who was also present in the audience and spoke during discussion

The event was also an opportunity to promote the annual *Proceedings* as a vehicle for publishing Queensland science and Honorary Editor Dr Barry Pollock spoke to the subject. The President and Dr Megan Evans, a University scientist presented on the intersection between science and policy.

COMMENTARY

An opinion piece by the President on the challenge presented by climate change was published in *The Courier-Mail* on 19 October 2017. The piece was followed by more than 500 online comments, a large proportion of them presenting what is known as the "climate denialist" viewpoint and many abusive.

On 14 January *The Sunday Mail* published an opinion piece from the President on the integrity of scientific research, particularly research claiming that the Great Barrier Reef is under considerable stress.

The online public policy newsletter *The Mandarin* published an opinion piece from the President on 21 September: "Pre-selection of candidates for political office is failing us" drawing attention to the difference between the credentials required of a candidate for preselection and the skills required of a minister once elected and promoted within the government. Given the decline in content-rich knowledge of the public service, it is all the more important that elected ministers have the skills to make prudent policy decisions.

Members Prof Ian Lowe and Maggie Muurmans as well as the President spoke at a forum on citizen science held on 11 August at Pullenvale by The Hut Environment and Conservation Association, Prof Lowe as keynote speaker.

Member Alan Lauder posted a weekly column on the website of the non-profit society Soils for Life, on the management of pastoral lands through the application of his carbon grazing principle, eventually completing 36 columns. These columns, explaining the distinction between carbon-stocks – central to carbon accounting – and carbon-flows – central to energising landscapes – were republished on the Society's website along with Mr Lauder's book *Carbon Grazing*. The columns offer an original perspective on the interaction between carbon, plant growth, animal digestion, methane emissions and the land.

RSQ WEBSITE

Supported by sponsor Avantix and a donation from a member, the Society's website was upgraded to include a facility for members to pay their membership fees online by PayPal or credit card without needing to make a bank transfer or send a cheque. Those other methods remain available.

A feature of the website is a Members' Collections head page, with a cluster of sub-pages available for members who have scholarly interests amenable to showcasing. Three additional members took advantage of this opportunity during the year and their pages are now being populated.

QUEENSLAND SCIENCE NETWORK WEBSITE

The Queensland Science Network consists of an unincorporated collaboration between 21 civil society groups primarily or prominently concerned with gathering and disseminating scientific knowledge. It is convened by the Society.

Thanks to the generosity of two anonymous donors, the Society commissioned consultants to develop a new website for the knowledge-based science societies. This site was switched live on 18 June, using the domain www.scienceqld.org.au. Each member organisation has an index page with a brief introduction to the group's activities and a link that switches inquirers to their homepage.

It is intended that this site will eventually become a prominent portal into non-government, non-university practical science. The site has the capacity to store an archive of documents such as citizen science reports and impact assessment studies that do not find their way into the peer-reviewed literature and may not be otherwise published.

Each of the member societies has a password to amend their own index page. A handful of higher-level passwords are available for a small group of experienced volunteer webmasters who will be entitled to manage the central repository including the News, Getting Involved, Resources library and other tabs. In September Member Shaun Davies generously offered to be one of the high level Webmasters.

RESEARCH FUND

Early in the year anonymous donations of $1000 and $35,000 were received for the Royal Society of Queensland Research Fund. Council also confirmed its previous decision to match a second tranche donation from the Central Queensland Koala Volunteers of $5000.

The total in the Fund having reached $57,000, which exceeds the threshold of $50,000 specified in the policy guidelines as the minimum above which grants can be disbursed, Council resolved to invite applications for up to $5000 per year for three years.

Applications were opened in June and closed on 31 July. The Minister for Environment and Science, The Hon Leanne Enoch MP, accepted an invitation to announce the awards at a ceremony in Parliament House on 31 October. The Society congratulates Alex Jiang of the University of Queensland and Chapa Gimhani Manwaduge of Queensland University of Technology on being the successful recipients of the inaugural awards. Their projects were on "Koala-cattle interaction" and "Conservation biology of threatened native olives (genus *Notolaea*) in southern Queensland" respectively.

GENOMICS COLLABORATION

A contract brokered by the Society was signed on 11 October at a ceremony in Central Queensland University's premises in Brisbane. Member Dr Alistair Melzer negotiated a deal to test tissue samples of koalas for genetic variation across their climatic range.

FINAL WORDS

This report highlights only the public activities and has named only a small handful of the members who have participated in its affairs. Networking amongst members, much of it behind the scenes, has been active throughout the year and many members have supported other members and have themselves been supported in their professional activities.

Although the Society includes amongst its membership some of Queensland's most eminent and productive researchers, many who have spent decades as 'top-shelf' researchers, it also has welcomed a steady enrolment of younger members and new members from fields of knowledge other than the traditional sciences. Council is proud that there are no elitist barriers to membership or to full participation in its activities.

The external political and policy environment for science remains enormously challenging, if anything more so than in 2017. The greatest regret of Council during the year is that it has lacked the resources to make better advantage of the depth of scholarship that lies within its members and its publications. A priority in the forthcoming year is to seek sponsorship and philanthropic donations to underpin an increased level of activity next year.

This Annual Report was compiled by Dr Geoff Edwards, President, on behalf of the Council of the Royal Society of Queensland. Dr Edwards has added a personal note: "I wish to place on record my gratitude to the Councillors who again during the year past have provided the cohesive and mature leadership that a learned academy requires in this era of disregard of objective scientific evidence and budgetary parsimony towards public good scientific institutions. I also wish to thank all those members who have attended events, have communicated by email and telephone or have simply shown their faith in the Society's mission by renewing their membership."

Date 10 October 2018

BOOK REVIEW: *A FIELD GUIDE TO SPIDERS OF AUSTRALIA*

Robert Whyte and Greg Anderson

CSIRO Publishing
ISBN: 9780643107076
464 pp

Initially flicking through this book, I became so excited that finally our beautiful spider fauna has been exposed for its true nature: incredibly diverse, often colourful and always uniquely adapted to their special part of the world! I am personally indebted to the authors that have achieved in one wonderful book, what I have aimed to convey to others all my arachnological life: that spiders are amazing and deserve much more appreciation and admiration than we begrudgingly bequeath them.

Thanks to the incredible patience and dedication of both Robert Whyte and Greg Anderson, the book is centered around 1,300 wonderful colour photographs of live Australian spiders - as never before captured. For the reader, this book delivers an insight into a world that only a small suite of enthusiasts and professionals had been previously privileged to experience. Extraordinary that they also snapped pictures of male spiders of many species, which are invariably short-lived and tricky to find.

Robert has well utilised his extensive background in science and journalism. Passionate about nature and ecological restoration, he has long been a champion for educating the Brisbane community on the special values of our waterways. Since 2012, Robert has also participated in the Australian Government led Bush Blitz expeditions which seek new species, including spiders. This was a great opportunity for him to expand his spider knowledge, photographic library and scientific connections. Clearly aided by his enthusiasm, Robert has built an extensive professional network, including with experts of particular spider groups in overseas museums that has ensured the scientific accuracy of this book's content. This is a rare achievement, as many other Australian spider books relied on limited professional advice, and even acknowledged small expert input to infer broader credibility of the text.

Whilst Professor Greg Anderson is otherwise an esteemed medical scientist at the Berghofer Queensland Institute of Medical Research, he has long been fascinated by spiders. Through extensive travels here and abroad, Greg has been dedicated to photographing, and learning more about spiders. As the reader can see in this book, he has a particular interest in members of the comb-footed family, to which the redbacks belong.

Whilst the authors have carefully delivered the information in a style to suit all readers, they have also not shied away from the science, explaining key anatomical terms and the basis of taxonomy – the description of new species. In fact, by clarifying how little we know "*The total number of Australian spider species is probably around 15,000 to 20,000. So far only 4,000 of them have been described..*" this book will hopefully encourage a new generation arachnologists. Perhaps a reader can aim for a place in our spider-discovering history, which the book outlines from the inaugural works of the Germans, Ludwig Koch and Eugen von Keyserling in the later 1800s, through to current publications by our respected arachnologists. This past has been infused elsewhere, such as in the photo caption for the spiny orb-weaver *Gasteracantha fornicata* (p95): "*This was the first Australian spider described...collected by Banks and Solander from coastal north Queensland on James Cook's voyage in 1770.*"

Information about the biology of spiders is well delivered from up-front sections on behaviour, webs or burrows, through to specific notes included in photo captions that highlight interesting facts. I felt that the section on spinnerets, the organs that produce silk (up to seven types for different uses), did not do justice to the importance of this trait in spider evolution and diversity. Equally, I felt that the general role of spider eyes in reflecting how they engage with their world, and for identification (most spider families have eight eyes, some have six and many cave dwellers have none) could have been better explained. Nonetheless, there is more detail provided for each family, sub-family or genus throughout the book, and

in photo captions. It is very helpful that spider size, in millimetres, is specified for each image given the large size range between species, or between males and females of one species.

The spider groups are arranged alphabetically by family throughout the main part of the book, including their sub-family groups of species. However, the more common families are separated from the lesser known families, which are again ordered alphabetically. Whilst I understand that the latter are encountered less often, I found this confusing and would have preferred to have all families in alphabetical sequence.

For the less experienced, there are also colour coded tabs on the pages that indicate general spider groups, such as orb weavers, crab spiders or mouse spiders. Unfortunately, the orange colour tab for the family Arkidae was missed in the legend. If you know the common name or scientific name though, you can use the comprehensive index, which is followed by very useful index of family common names. A family tree is included at the very end which illustrates the current understanding of how all the Australian families are related: to insects and other invertebrates; to other arachnids, and; to other families within the more primitive sub-order Mygalomorphae or the more evolutionarily advanced sub-order Araneomorphae.

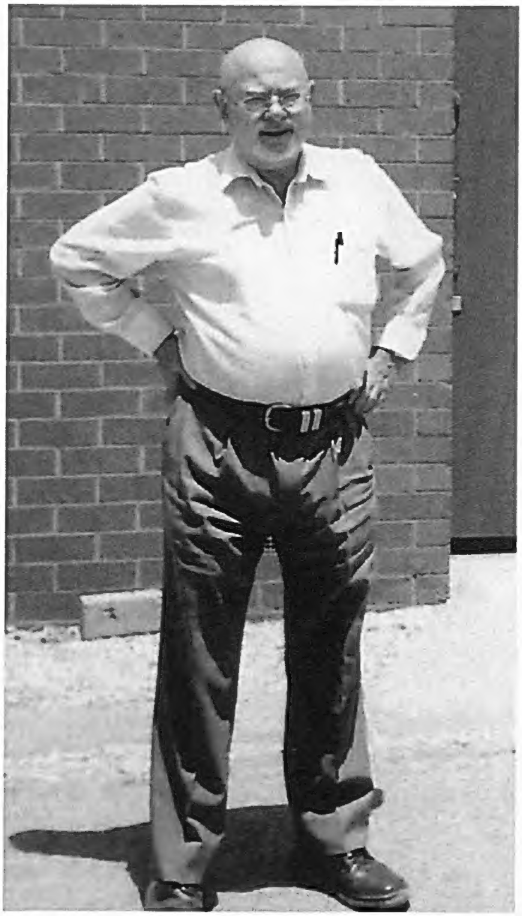
On a technical level, I must note that the genus *Idiommata* was incorrectly attributed to the family Idiopidae, instead of Barychelidae (p 45). However, it must only have been an editing oversight, as it is given the right common name for barychelids, and was not suffering from an such an identity crisis in the barychelid section (p 384). Whilst the "scary looking" trapdoors and tarantulas are treated with the respect they deserve, there is unfortunately no information on their conservation status. With the significant impact that collecting for the pet trade has had on tarantula populations, and the possible extinction of species, it would have been helpful to educate the interested public of their plight, through such a valuable reference book.

The amazing richness of the fauna is well exemplified through the many photos of species in two groups: classic orb-weavers (Family Araneidae, subfamily Araneinae) and jumping spiders, family Salticidae. Salticids include the incredibly colourful Peacock spiders that recently acquired social media fame through Jürgen Otto's YouTube videos of their playful courtship behaviour. Whilst they very diverse, they are clearly Robert Whyte's favourite spiders with almost a fifth of the book dedicated to salticid images! If the pretty spiders don't tame the arachnophobes, perhaps the unusual spiders can, such the scorpion tails (p 54-55), lichen mimic (p 51) or mimics of the green headed ant (p130), northern green tree ant (p281) or green tree ant (p 350). At least the authors dispel the myths that promote public fear of spiders, such as that of white-tailed spiders causing rotting flesh and of daddy long-legs having high venom toxicity.

So the secret is out: our spiders are actually fascinating and offer a lifetime of discovery for both scientists and naturalists. I highly recommend this book, which you can trust to be the current authoritative reference on Australian spiders for your children, your community group or your own backpack!

ABOUT THE REVIEWER:
Dr Tracey Churchill has a Bachelor of Science, and first class Honours and Doctorate degrees in spider ecology. Tracey led the Australasian Arachnological Society for 5 years, producing and editing their regular publication, and was elected onto the Executive Council of the International Arachnological Society. Tracey introduced the use of spiders as ecological indicators of ecosystem health to Australia and developed this science as a Research Scientist with the CSIRO Sustainable Ecosystems in Darwin over five years. Tracey has also been a taxonomist, describing new genera and species of mygalomorphae with Dr Robert Raven of the Queensland Museum. In recognition of her contribution to arachnology other specialists have named four spider species after her across four different spider families. Whilst Tracey now works for Queensland National Parks and Wildlife, she continues to educate the public, friends and family about the amazing diversity of spiders whenever possible.

OBITUARY OF HARRY WILLIAM BREYDON "DON" EASTWELL
21st October, 1934 – 10th April, 2018



Don was born at Warwick on 21st October, 1934 – Trafalgar Day, the only child of Leslie Burt Eastwell and Gwendoline Thompson Eastwell (née Williams).

He grew up at 96 Guy Street, Warwick with his parents and pet cocker-spaniel Kim. His grandfather "Pop" Williams lived with them for some years.

Don's primary schooling was at the Warwick Central State School and the Warwick Intermediate where he sat for and passed the public Scholarship Examination. His secondary schooling was at Warwick State High School where he followed the academic strand, matriculated and proceeded to study medicine.

His lifelong interest in palaeontology arose from his studying geology as a subject for Senior; he was taught by Robert J. Young who passed on the joys of geology to many of his students. It is noteworthy that Don's mother Gwen had been one of the first women to take the subject at the University of Queensland when she completed her Arts Degree in the1920s.

Don was active in extracurricular fields during his school years. He was in the wolf cubs and scouts in 8th West Warwick, of which his father was Group Scout Master "Beaver". His mother also played an active role as Cub Mistress "Baloo".

During that time, Don also took piano lessons from Mrs. Colleen Bloomfield, achieving his Associate Diploma of the London College of Music. This developed his love of classical music.

Having been in Warwick State High's army cadet unit, Don fulfilled his National Service obligations at the National Service Training Battalion at Wacol, then in the Queensland University Regiment, where he had the rank of Corporal.

After graduating with his M.B., B. S., Don married Marjorie Elizabeth Hodgson of Toowoomba on 13th December, 1958. They were heading for their diamond wedding anniversary later this year.

Don was a long-standing member of the Royal Society of Queensland until his death. He served as a member of the Editorial Board from volume 111 (2002) until volume 116 (2011) (except for the bushfire Special Issue volume 115 of 2009).

Time is the fourth dimension. We all live on the soil, sand and rocks from which they were derived. We all live in the biosphere. We should all do our best to learn and understand our place.

Don did that.

He is survived by his wife Marjorie and son Steven.

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